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The World Nuclear Industry
Status Report 2023

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The World Nuclear Industry Status Report 2023

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NOTE

This report contains a very large amount of factual and numerical data. While we do our utmost to verify and double-check, nobody is perfect. The authors are always grateful for corrections and suggested improvements.

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FOREWORD

by Stephanie Cooke[1]

Truth has rarely been a friend to nuclear power and for that reason it hasn't always been easy to find accurate information about the industry's vital signs. This is why the World Nuclear Industry Status Report (WNISR) is essential reading for anyone trying to understand the current state of the commercial nuclear power industry. Prior to its regular annual publication since 2007, inquiring minds were forced to rely on official reports by nuclear-friendly organizations or embark on major research efforts of their own. The WNISR, with its wealth of reportage from nuclear experts across the global nuclear landscape, has made that task much easier.

Much has changed since I began covering the industry as a journalist in 1980. The United States still dominated the industry, promoters held fast to the notion that a reactor could never "blow up like a bomb"—until one did in 1986—and the separation of nuclear energy's "peaceful" and military sides was considered sacrosanct. It would have been inconceivable to hear anyone in the U.S. argue that a strong civilian nuclear sector is vital to supporting national security and nuclear weapons as former Energy Secretary Ernest Moniz did in a 2017 report. It also would have been inconceivable to imagine the U.S. without a commercial uranium enrichment operation that had dominated Western nuclear fuel markets since the earliest days of nuclear power. Nor would it have been easy to imagine Westinghouse and GE [General Electric] losing ground to a mightier rival in Russia, or seeing China in 2022 generate more nuclear electricity than France—second only to the U.S.—for the third year in a row.

The Western nuclear industry rode out the Chernobyl disaster by blaming it on shoddy Russian technology; that argument didn't work after the 2011 triple meltdown at the GE-designed Fukushima plant in Japan. Still, the industry has never tired of proclaiming nuclear reactors safe, and who could have foreseen their strategic and tactical value to Russian military forces invading Ukraine?

The changes have been immense. Yet in its broader characteristics, the global nuclear power industry today remains much as it was then--opaque when it comes to costs and timetables, prone to wildly inflated growth forecasts, and stubbornly fighting the rapid growth in renewables, although the gaps between the two in terms of growth, cost and performance widen by the year.

Nuclear energy remains an expensive and dangerous proposition financially, environmentally and now militarily, with insufficient liability protection and prospects of future Black Swan events that destroy whole regions, uproot populations, increase cancer occurrence, and threaten even distant ecosystems. Japan began releasing partially decontaminated water into the Pacific Ocean on 24 August 2023 and will continue the operation for at least three decades to dispose of some 1.3 million tons stored at the Fukushima site. It partially justified the action by citing the fact that all reactors release tritium into the environment, as if this somehow makes it more acceptable.

1 - Opinion Columnist for *Energy Intelligence*; Former Editor, *Nuclear Intelligence Weekly*.

Bizarrely, nuclear energy is riding a new wave of popularity, and is seen by many policy planners and energy experts as part of the solution to reducing carbon emissions based on industry claims that it is both "clean" and "reliable". However, given its long lead times and exorbitant costs the prospect of this happening is virtually zero. Moreover, climate impacts, such as cooling water availability, heat sink capacity and storms, also threaten the performance and safety of nuclear reactors.

My own view is that the intense debate that surrounds nuclear energy is a major distraction to known—and achievable—solutions such as transformed transmission, distributed resources and, so long as the energy they produce can get to end users, renewables.

The U.S. is in theory 90% of the way toward meeting President Joe Biden's goal of a zero-carbon power sector by 2035, with more than 2 terawatts of mostly renewable energy projects looking for access to the grid--almost double current U.S. generating capacity of 1.25 terawatts. But based on prior experience, only a fifth of that capacity will make it onto the system, according to a Berkeley Lab April-2023 report. The problem isn't lack of generation; in part it's lack of transmission lines that can carry renewables like wind from remote regions of the country to where it's needed, and developers trying to provide them are trapped in bureaucratic limbo because of an electricity system that is carved up by regions and sometimes individual states, dominated by entrenched interests and choked by layers of regulations.

Since the start of the current millennium, more than [US]$50 billion was spent in the U.S. to resuscitate a dying nuclear industry and that only includes what was spent on the twin AP-1000 projects at Vogtle in Georgia and V.C. Summer in South Carolina, completing the long-delayed Watts Bar-2 in Tennessee, and upgrading two plants in Florida. Untold millions were spent filing applications for new reactors meant to create a new Golden Age for nuclear. Apart from 1 GW each from Watts Bar-2 and Vogtle-3, and the prospect of another gigawatt from Vogtle-4, there is nothing to show for that outlay. V.C. Summer collapsed, the two Florida plants were permanently closed, and the new reactor applications mostly collected dust at the U.S. Nuclear Regulatory Commission.

Billions more are being spent on SMRs and advanced reactors, the prospects for which are questionable at best. If NuScale couldn't launch a small version of conventional light-water reactor technology, what are the chances of success for the more exotic and dated technologies currently on dozens of drawing boards in at least nine countries? One U.S. SMR developer told *Forbes* earlier this year that there "will be five or 10" SMRs by 2030--and that within 5-10 years after that "there will be a real hockey stick in terms of growth." I wouldn't bet on it.

Meanwhile, to keep struggling reactors operating, the U.S. is spending billions in state and federal subsidies, amidst headline-grabbing corruption scandals and prison sentences connected to some of this spending, and to the failed [V.C.] Summer project. NuScale itself faces lawsuits from shareholders claiming they were misled.

From both economic and geopolitical perspectives, nuclear industries sit more comfortably within state-controlled organizations supported by the public purse—hence China outpaces every other country by a long mile with 23 reactors under construction domestically, and Russia dominates the international market with 24 units under construction (as of mid-2023), of which only five are being built domestically. Only two other companies, French and South

Korean, are building abroad—in the UK and UAE, respectively—and both are government-owned. The WNISR estimates that roughly 45 percent of global nuclear capacity is fully state-owned.

Nuclear projects are seen as a means of long-term geopolitical influence, but geopolitics—such as the impact of sanctions—can also work to the supplier country's disadvantage. The costs of such projects may ultimately prove too crushing to bear even for centrally-controlled economies. Payments disputes have delayed Russia's twin-unit project at Bushehr in Iran, and various political disputes have threatened Russia's progress in Turkey. Unwisely, the U.S. thinks it should follow the Russian model by supporting nuclear projects in eastern Europe via its own export credit agencies. But governments change and so do their energy plans, which puts that public financing at risk.

Earlier this year, the U.S. Department of Energy suggested that a total 300 GW of new nuclear energy would be needed in the U.S. by 2050 to make an impact on reducing carbon emissions. This would be more than twice the number of reactors ever built in the country and, based on Vogtle's costs of roughly US$17.5 billion per gigawatt, would cost up to US$5.25 trillion. It would also require a permanent tax to finance—and that would only cover construction. What about decommissioning, the costs for which vary widely, and waste management, already estimated at up to US$168 billion (in 2018 dollars and not adjusted for inflation) in an early next-century disposal scenario?

This proposal is out of step with our times, and serves only to deflect attention from realistic and affordable solutions to climate change. Irrespective of the current craze for SMRs and advanced reactors, most investors are still not convinced that nuclear will pay off in competitive power markets, and the business models suggested for non-power use—such as crypto mining, hydrogen, process heat, and water desalination—are hugely capital intensive and therefore unlikely to depend on expensive nuclear power.

Globally, the money that went into non-hydro renewable electricity capacity reached a record US$495 billion in 2022, up 35 percent from the previous year and 74 percent of all power generation investments that year. By contrast, only US$35 billion was committed to new nuclear power plant construction (representing just 9.4 GW) in that same period. Renewables (including hydro) added 348 GW of new capacity in 2022 compared with a net addition of 4.3 GW in operating nuclear power capacity.

With improving load factors, wind and solar combined outperformed nuclear globally for the first time in 2021, and in 2022 they generated 28 percent more electricity than nuclear plants, the WNISR reports. Globally, nuclear accounted for 9.2 percent of the power mix, while non-hydro renewables increased to 14.4 percent. Solar alone outpaced nuclear in China for the first time in 2022 as it already had in India, and solar and wind together produced more power than nuclear in the European Union.

The urgent need for action on climate change demands doable, affordable solutions, and accurate information about what's on offer, its record of performance, cost and length of time to deploy. The WNISR argued for the better part of a decade to convince the International Atomic Energy Agency to more accurately portray nuclear energy's contribution to global electricity output, by not including dormant reactors (primarily those closed in the aftermath of Fukushima that have never restarted) in its count. Finally, in 2022 the agency began to exclude such reactors from its count and is now virtually in line with the WNISR's assessment of total global operating nuclear capacity.

These numbers point to the inexorable rise of 21st century energy strategies that no longer need to rely on baseload power, and can instead focus on renewables, modernized flexible grids and achieving energy efficiencies.

KEY INSIGHTS

Nuclear Production Sees Biggest Slump in a Decade - Share Drops to Lowest Point in Four Decades

- Global nuclear power generation dropped 4 percent; outside China, it declined by 5 percent to a level last seen in the mid-1990s.
- Nuclear energy's share of global commercial gross electricity generation in 2022 dropped to 9.2 percent—the largest drop since post-Fukushima year 2012 and a four-decade record low—and little more than half of its peak of 17.5 percent in 1996.
- As of mid-2023, 407 reactors with 365 GW were operating in the world, four less than a year earlier, 31 below the 2002-peak of 438.
- Seven units were connected to the grid and five were closed in 2022. Four new reactors started up in the first half of 2023 and five were closed.
- Over the two decades 2003–2022, there were 99 startups and 105 closures worldwide: 49 startups in China with no closures; outside China, a net decline of 55 units and a net drop of 24 GW in capacity.
- The International Atomic Energy Agency (IAEA) significantly revised its statistics, now showing the peak in officially operating reactors as early as 2005 with 440 units (close to WNISR's 438 in 2002).

Major National Developments in 2022

- **Belgium**. One reactor was closed in September 2022, and another one in January 2023. Three of the remaining five units are to close by 2025, while operation of the two most recent ones is to be extended until 2035.
- **France**. Nuclear generation dropped below the level of 1990. Compared to 2010, output plunged by 129 TWh, much more than the 100 TWh Germany lost in nuclear production due to its phaseout policy over the same period. For the first time since 1980, France turned into a net importer of electricity. Threatened by bankruptcy over record losses and unprecedented net debt levels (US$70 billion as of mid-2023), the utiliy company EDF was renationalized.
- **Germany**. The three last operating reactors were closed on 15 April 2023, twelve years after the definitive phaseout policy was decided in 2011.
- **South Korea**. State-owned utility KEPCO filed a record loss of US$$_{2022}$25 billion with net debt rising by 32 percent to an unparalleled US$$_{2022}$149 billion.
- **United Kingdom**. Only nine units remain operating. The cost estimate for two reactors under construction at Hinkley Point C has reached US$$_{2021}$44 billion in February 2023, with first grid connection delayed to June 2027.
- **United States**. Nuclear share of commercial electricity generation declined to 18.2 percent, its lowest level in 25 years. After 10 years of construction, the first of two new reactors at Plant Vogtle was connected to the grid in April 2023. Cost estimates for the two units exceed US$35 billion.

Russia Continues to Dominate the International Niche Market

- As of mid-2023, China had the most reactors under construction (23) but is not building any abroad. Russia is dominating the international sellers' market with 24 units under construction of which 19 units in seven other countries, including China (4).
- Construction started on 10 reactors in 2022, and three in the first half of 2023; of these, seven are in China (five in 2022 and two in 2023).
- At least 24 of the 58 ongoing construction projects are delayed. Of these, at least nine have reported *increased* delays and one has reported a delay for the first time.
- 90 percent of all ongoing construction projects are carried out either in Nuclear Weapon States (NWS) or by companies controlled by NWSs in other countries.
- At the beginning of 2022, 16 reactors were planned to be connected to the grid within the year but only seven of these started generating power.

Fukushima Status

- Beginning of spent fuel removal from pools of Units 1 and 2 was delayed to 2027 and not to be completed before 2031. Fuel debris removal has also been pushed into the future.
- The controversial discharging of the first batch of the 1.3 million tons of contaminated water to the ocean has started in August 2023. The release is to take 30 years.
- About 27,000 former residents of Fukushima Prefecture are still living as evacuees.

Decommissioning Status

- The number of closed power reactors reached 212 units as of mid-2023. Of these, only 22 reactors have been fully decommissioned; only 11 units have been released from regulatory control.

Small Modular Reactors (SMRs)

- The 2023-update does not reveal any major advances. In the western world, no unit is under construction, and no design has been fully certified for construction. The most advanced project, involving NuScale in the United States, was terminated in November 2023 following a 75 percent increase of the cost estimate.

Nuclear Economics and Finance

Nuclear power is increasingly under pressure from a wide range of other, innovative options for electricity generation and other ways of affecting the cost and reliability of energy services.

- **Public Financing**. About 45 percent of the world's nuclear capacity is already fully state-owned. Almost all the ongoing construction projects are implemented through public companies and/or involve public finance.
- **Massive Subsidies**. In the U.S., state-level taxpayer-funded subsidies granted to 19 reactors are estimated to exceed US$15 billion by 2030. In addition, federal subsidies offer up to US$15/MWh for plants operating from 2024 to 2032.
- **Levelized Cost of Energy (LCOE)**. Modeling by Lazard indicates that at discount rates of more than 5.4 percent, nuclear power is the most expensive generator. At a discount rate of 10 percent, nuclear is nearly four times the LCOE of onshore wind. Adding rapidly declining firming (grid balancing) costs (like storage or complementary power purchase) to unsubsidized solar and wind in the U.S. at *combined* cost of US$45–140/MWh is always cheaper than new nuclear at mean US$180/MWh.

Missing and Underestimated Costs.

- **Decommissioning**. A detailed reactor-level WNISR analysis estimated decommissioning costs for the three nuclear phaseout countries Germany, Italy, and Lithuania at around US$$_{2020}$6.8/MWh, US$$_{2020}$16/MWh, and US$$_{2020}$15.7/MWh, respectively, at least an order of magnitude larger than most international estimates.
- **Liabilities for Accidents.** The Japanese Government estimated the cost of the 2011 Fukushima accidents at US$$_{2021}$223 billion, more than sixteen times the total U.S. insurance pool of US$13.6 billion, the largest in the world.

Renewable Energies Orders of Magnitude Ahead of Nuclear Power

- In 2022, total investment in non-hydro renewable electricity capacity reached a new record of US$495 billion (+35 percent), 14 times the reported global investment decisions for the construction of nuclear power plants. Wind and solar facilities alone generated 28 percent more electricity than nuclear plants and reached a 11.7 percent share of electricity generation, with nuclear shrinking to 9.2 percent.
- In **China**, solar PV produced a total of 423 TWh of electricity in 2022, for the first time overtaking nuclear power that generated 397 TWh. In **the European Union**, solar and wind plants together produced 624 TWh, for the first time exceeding not only nuclear energy (613 TWh) but also natural gas (557 TWh) and coal generation (447 TWh), while all renewable sources accounted for over 38 percent of the E.U.'s electricity production. In **India**, wind and solar plants together produced 3.7 times more power than nuclear reactors in 2022 Wind has outpaced nuclear in power generation since 2016. Solar passed nuclear generation in 2019.

EXECUTIVE SUMMARY AND CONCLUSIONS

Following the worst COVID-19 pandemic years 2020–2021, 2022 was largely dominated by the effects of a global energy crisis exacerbated by the war in Ukraine. For the first time in history, operating commercial nuclear facilities were directly attacked and then occupied by hostile forces during a full-scale war. As of the end of 2023, while attracting little attention in recent months, the occupation of the Ukrainian nuclear power plant Zaporizhzhia is still ongoing, the threats of cuts of power and water supplies persist. The specific risks to a nuclear plant in a full-scale war have been analyzed in detail in WNISR2022.

The World Nuclear Industry Status Report 2023 (*WNISR2023*) provides a comprehensive overview of nuclear power plant data, including information on age, operation, production, and construction of reactors. WNISR2023 includes a special focus chapter assessing Nuclear Economics and Finance.

WNISR2023 analyses the status of newbuild programs in 13 of the 32 nuclear countries (as of mid-2023) as well as in Potential Newcomer Countries. WNISR2023 includes sections on 12 Focus Countries representing almost one third of the current nuclear countries—plus Germany that closed its last reactor in April 2023 and Poland that, once again, envisages the construction of its first reactors—72 percent of the global reactor fleet, and the world's five largest nuclear power producers. The comprehensive special United States Focus provides a detailed analysis of the status of the U.S. nuclear program as well as the multiple federal and state-level support initiatives for the sector. For the first time, the Focus Countries chapter includes a section on South Africa.

The situation of Small Modular Reactor (SMR) development is analyzed in a dedicated chapter. The status of onsite and offsite challenges are summarized in the Fukushima Status Report. The Decommissioning Status Report provides an overview of the current state of nuclear plants that have been permanently closed. The chapter on Nuclear Power vs. Renewable Energy Deployment offers comparative data on investment, capacity, and generation from nuclear, wind, and solar energy, as well as other renewables around the world. Finally, Annex 1 presents overviews of nuclear power programs in the countries not covered in the Focus Countries chapter.

PRODUCTION AND ROLE OF NUCLEAR POWER

Prior to the entry into force of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) in 1970, 14 countries were operating nuclear power reactors. By 1985, 16 additional countries had reactors on the grid. Over the 30-year period 1991–2020 (none in 2021), only five countries started up their first power reactors—China (1991), Romania (1996), Iran (2011), United Arab Emirates (UAE), and Belarus (both 2020); in 2021–2022, no newcomer country started any reactor. Four countries abandoned their nuclear power programs, Italy (1987), Kazakhstan (1998), Lithuania (2009), and Germany (2023).

Reactor Operation and Capacity. As of 1 July 2023, a total of 407 reactors—excluding Long-Term Outages (LTOs)—were operating in 32 countries, four units less than in WNISR2022,[1] eleven less than in 1989, and 31 below the 2002-peak of 438. At the end of 2022, the nominal net nuclear electricity generating capacity had peaked at 368 GW,[2] having added 5.3 GW during the year, 1 GW more than the previous 2006-record of 367 GW, but it dropped again to 364.9 GW by mid-2023.

IAEA versus WNISR Assessment. Between September 2022 and April 2023, the International Atomic Energy Agency (IAEA) significantly modified its statistics—including retroactively—as displayed in its online-Power Reactor Information System. This in turn impacts the perception of nuclear industry trends. Until September 2022, PRIS showed a historic peak in officially operating reactors, both in terms of number (449) and capacity (396.5 gigawatt), in 2018. In July 2023, PRIS shows the peak in the number of units occurring as early as 2005 at a maximum of 440 and the maximum capacity still in 2018 at 374 GW. Both indicators have declined since, with PRIS showing 410 units as operating with 368.3 GW of capacity as of mid-2023.

Until September 2022, the IAEA had included 33 units in Japan in its total number of reactors "in operation" in the world while only 10 of these units had effectively restarted and 23 have not produced electricity at least since 2010–2013 (of which, three since 2007). As of mid-2023, the IAEA had pulled those 23 units, together with four reactors in India, from the list of operating reactors retroactively since shutdown and added them to a new category labelled "Suspended Operation".

WNISR had called on the IAEA to adapt its statistics to industrial reality since 2014 when it created its own Long-Term Outage (LTO) category. As of mid-2023, WNISR classified 31 units as LTO, of which 23 in Japan, three in India, two in Canada, and one each in China, France, and South Korea—the number increased by two compared to WNISR2022.[3]

Nuclear Electricity Production. In 2022, the world nuclear fleet generated 2,546 net terawatt-hours (TWh or billion kilowatt-hours) of electricity. Production dropped by 4 percent compared to 2021 to the level of pandemic-year 2020. China continued to generate more nuclear electricity than France for the third year in a row and remains second—behind the United States (U.S.)—in countries operating nuclear power plants. Outside of China, nuclear production dropped by 5 percent in 2022 to a level last seen in the mid-1990s.

Share in Electricity/Energy Mix. Nuclear energy's share of global commercial gross electricity generation in 2022 dropped by 0.6 percentage points—the largest drop since post-Fukushima year 2012—to 9.2 percent, 47 percent below the peak of 17.5 percent in 1996.

1 - Difference WNISR2022–WNIR2023: Six reactor startups +1 restart –3 new LTO –8 closures = -4

2 - Difference as of year-end 2021 and 2022: Seven reactor startups +7.6 GW, five reactor closures –3.3 MW and one LTO restart +1 GW

3 - As of early November 2023, the two Canadian, two Japanese, and the French unit had been reconnected to the grid.

REACTOR STARTUPS AND CLOSURES[4]

Startups. In 2022, seven reactors were connected to the grid, of which three were in China and one each in Finland, Pakistan, South Korea, and the UAE. In the first half of 2023, four units were connected to the grid, one each in Belarus, China, Slovakia, and the U.S.

Closures.[5] In 2022, five reactors were closed, three in the United Kingdom (U.K.), and one each in Belgium and the U.S. In the first half of 2023, another five units were closed, three in Germany and one each in Belgium and Taiwan.

Over the two decades 2003–2022, there were 99 startups and 105 closures. Of these, 49 startups were in China which did not close any reactors. As a result, outside China, there has been a drastic net decline by 55 units over the same period, and net capacity declined by over 24 GW.

CONSTRUCTION DATA[6]

As of 1 July 2023, 58 reactors (58.6 GW) were under construction, that is five more than in last year's WNISR, but 11 fewer than in 2013 (five of those units have subsequently been abandoned).

Four in five reactors are being built in Asia or Eastern Europe. 16 countries are building nuclear plants, one more than in WNISR2022. The list includes Egypt and the construction restart in Brazil but leaves out Belarus since it completed its second unit. Only four countries—China, India, Russia, and South Korea—have construction ongoing at more than one site. Construction started on ten reactors worldwide in 2022: five are in China while the other five are implemented by Russia in Egypt (2), in Turkey (1), and domestically (2). The building of three reactors got underway in the first half of 2023, two of them in China, and one by Russia in Egypt. Chinese and Russian government-owned or -controlled companies were responsible for all 28 reactor construction-starts in the world over the 42-month period from the beginning of 2020 to mid-2023.

Building vs. Vendor Countries

- As of mid-2023, China had by far the most reactors under construction with 23 units or 40 percent of the total. However, China is currently not building anywhere outside the country.
- Russia is the dominant supplier the international market with 24 units under construction in the world as of mid-2023. Five of these are being built domestically. The remaining 19 units are being constructed in seven countries, including four each in China, India, and Turkey, as well as three in Egypt.[7] It remains uncertain to what extent these projects have or will be impacted by sanctions imposed on Russia and other consequential geopolitical developments following the invasion of Ukraine.

4 - See Focus Countries and Annex 1 for a country-by-country overview.

5 - WNISR accounts for closures in the respective years of last electricity generation and adjusts statistics retroactively if units have not generated power in the year in review.

6 - See Annex 3 for a detailed overview of the 58 reactors under construction in the world as of mid-2023.

7 - Two units are under construction in Bangladesh and one each in Iran and Slovakia.

- Besides Russia's Rosatom, only French and South Korean companies are acting as leading contractors building nuclear power plants abroad; France in the U.K. and South Korea in the UAE.[8]

Construction Times

- For the 58 reactors being built, an average of six years has passed since construction start—lower than the mid-2022 average of 6.8 years—but many remain far from completion.
- *All* reactors under construction in at least 10 of the 16 countries have experienced often year-long delays.
- Of the 24 reactors clearly documented as behind schedule, at least nine have reported *increased* delays and one has reported a delay for the first time over the past year.
- WNISR2021 noted a total of 12 reactors scheduled for startup in 2022. At the beginning of 2022, 16 were planned to be connected to the grid within the year (including four pushed back from 2021 to 2022) but only seven of these generated first power; the other nine were delayed at least into 2023.
- Initial construction of the Mochovce-4 reactor in Slovakia started 38 years ago and its grid connection has been further delayed, currently to 2024. Bushehr-2 in Iran originally started construction in 1976, over 47 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2024.
- Seven additional reactors have been listed as "under construction" for a decade or more: Angra-3 in Brazil, the Prototype Fast Breeder Reactor (PFBR), Kakrapar-4, and Rajasthan-7 & -8 in India, Shimane-3 in Japan, and Flamanville-3 (FL3) in France. The French and Indian projects have been further delayed this year, and the Japanese reactor does not even have a provisional startup date.

Construction Starts

- Construction started on ten reactors in 2022, including five in China. Russia began work on reactors in Egypt (2), in Turkey (1) and in Russia (2), and on a barge in China which is to be equipped with two reactors in Russia.[9] In other words, of the global total of ten, seven reactors were designed by the Russian and three by the Chinese industry.
- Construction of three reactors started in the first half of 2023, two of them in China, and one of Russian design in Egypt.
- Chinese and Russian government-owned or -controlled companies launched all of the 28 reactor constructions in the world over the 42-month period from the beginning of 2020 to mid-2023.

OPERATING AGE

- The average age (from grid connection) of operating nuclear power plants has been increasing since 1984 and stands at 31.4 years as of mid-2023, up from 31 years in mid-2022.

8 - A Czech-led consortium is completing a Russian-designed reactor (Mochovce-4) in Slovakia.

9 - Keel laying is considered construction start for floating reactors.

- A total of 265 reactors—five less than mid-2022—two-thirds of the world's operating fleet, have operated for 31 or more years, including 111—more than one in four—for at least 41 years.
- If all currently licensed lifetime extensions and license renewals were maintained, all construction sites completed, and all other units operated for a 40-year lifetime (unless a firm earlier or later closure date has been announced), in the years to 2030, the net balance of operating reactors would turn negative as soon as 2024, and slightly positive for the years 2026–2027; but overall, an additional 88 new reactors (66.5 GW)—almost one unit or 0.7 GW per month—would have to start up or restart to replace closures. This would necessitate almost doubling the annual startup rate of the past decade from six to eleven over the remaining period to 2030 just to maintain the current number of reactors in the world. Considering the long lead times, this appears to be a highly unrealistic scenario.

FOCUS COUNTRIES

The following 11 Focus Countries include those home to almost one third of the current nuclear countries as well as Germany that closed its last reactors in April 2023 and Poland which plans to build its first reactors. Some key developments in 2022 and the first half of 2023:

Belgium. Nuclear generation dropped by 13 percent in 2022. Under the framework of the phaseout policy, one reactor was closed in September 2022, and another one in January 2023. Five reactors remain operational. The current plan is to close three by 2025 and extend operation by 10 years for the two most recent ones to 2035. A legally binding agreement is expected to be closed in early 2024.

China. Nuclear power generation increased by 3.2 percent—a modest development compared to the 11-percent boost in 2021—and provided a stable 5 percent of total electricity generation. Meanwhile, wind energy output grew by 16 percent and solar by 31 percent. Non-hydro renewables produced 15.5 percent of national gross power generation, more than three times the nuclear contribution.

France. After experiencing a declining performance since 2015, the year 2022 represented an "annus horribilis", in the words of an EDF director. Due to a cumulation of generic technical failures, issues related to ageing, climate impact, and social movements, nuclear generation dropped below the level of 1990 or about 120 TWh below the 2005–2015 level of around 400 TWh. That drop in output is larger than the 100 TWh Germany lost in nuclear generation since 2010 due to its phaseout policy. On average, French reactors generated zero power on 152 days in 2022. For the first time since 1980, France turned into a net importer of electricity, with Germany playing a key role as an exporter. Utility Électricité de France (EDF), facing potential bankruptcy over record losses and unprecedented net debt levels (€$_{2023}$64.8 billion or US$70 billion as of mid-2023), was renationalized.

Germany. The country's nuclear fleet generated 32.8 TWh net in 2022, a decline by half over the previous year after three reactors were closed at the end of 2021, and only a fraction of the peak generation of 162.4 TWh in 2001. Nuclear plants provided 6 percent of Germany's gross electricity generation, compared to the historic maximum of 35.6 percent in 1999. The three last operating reactors were closed on 15 April 2023, 62 years after nuclear electricity was first generated in the country.

Japan. No additional reactor has been restarted since WNISR2022 (none was slated for closure). A mere 10 units are considered operational with 23 in LTO as of mid-2023. After a major increase in 2021, nuclear generation dropped again (-15.3 percent) to provide 6.1 percent (-1.1 percentage points) of the country's electricity. A special investigation committee found hundreds of falsification cases at Japan Steel Works, one of the most important manufacturers of large forgings which have been supplied to nuclear power plants around the world.

Poland. In October 2020, the government adopted a long-term Polish Nuclear Power Program aiming to commission 6–9 GW of nuclear capacity by 2043. The country abandoned construction of two Russian-designed VVER reactors in the 1980s, and several subsequent relaunch attempts were aborted. Meanwhile, Poland has one of the fastest growing solar programs in the E.U. increasing capacity by 61 percent in 2022 to reach 12.4 GW.

Russia. Nuclear power generation increased slightly to reach a new record of almost 210 TWh. The country operates 37 reactors and has a further five under construction. Abroad, Russia maintained its role as the leading nuclear power plant builder in the world with 19 units under construction in seven countries as of mid-2023. Eight European countries, including four in the E.U., remain highly dependent on Russian fuel assemblies for 38 operating reactors.

South Africa. Nuclear generation dropped by 17 percent to just over 10 TWh providing 4.9 percent of electricity. The drop was the result of lengthy outages for extensive refurbishment in view of a 20-year lifetime extension, coupled with unplanned outages due to technical incidents. As the country's large fleet of coal plants also experienced severe technical problems, the country was faced with severe power shortages.

South Korea. Nuclear power production increased by 11.3 percent to 167.5 TWh providing just over 30 percent of the electricity in the country. The increase is due to the startup of one new reactor (Shin-Hanul-1) and the better performance of some units. However, state-owned utility KEPCO filed a record loss of US$$_{2022}$25 billion with its net debt jumping by 32 percent to an unprecedented US$$_{2022}$149 billion. KEPCO stock lost 70 percent of their value over the past seven years.

United Kingdom. The nuclear program is shrinking rapidly. Two additional reactors have closed since WNISR2022, leaving only nine units operating. In total, there are now 36 closed units awaiting decommissioning, the second largest number after the U.S. The nuclear share in the electricity mix has almost halved since 1997 when it made up 28 percent. However, due to the dramatic production plunge in France, in 2022, the U.K. turned into a net power exporter in 2022 for the first time in four decades. Meanwhile, following repeated delays, the cost estimate for the two reactors under construction at Hinkley Point C has continued to rise and reached US$$_{2021}$44 billion in February 2023, with grid connection of the first unit planned for June 2027 at the very earliest.

United States. Nuclear output declined slightly (-0.9 percent) to 771.5 TWh, the lowest in a decade. The nuclear share of commercial electricity generation declined to 18.2 percent, its lowest level in 25 years. The U.S. nuclear fleet is still the largest in the world, with 93 units, and one of the oldest with a mean age exceeding 42 years. After 10 years of construction, the first of two new reactors at Plant Vogtle was connected to the grid in April 2023. All-in cost estimates for the two Vogtle units now exceed US$35 billion. Substantial new subsidy programs for uneconomic operating reactors and for new projects have been further expanded at the federal and state levels and are impacting previous retirement planning. Over the past five years, the seven closed reactors averaged an operational age of just over 47 years, far below their licensed lifetimes of 60-years. Emerging business models include the coupling of nuclear output with projected consumption by data centers, crypto mining, or hydrogen production. Various criminal investigations continue to plague the nuclear sector. In March 2023, the former CEO of the utility in charge of the later abandoned V.C. Summer newbuild project was sentenced to 15 months in prison, the payback of US$1 million in "ill-gotten income", and a US$200,000 fine for lying on the real construction status of the project.

FUKUSHIMA STATUS REPORT

Eleven years have passed since the Fukushima Daiichi nuclear power plant disaster began, triggered by the East Japan Great Earthquake on 11 March 2011 (referred to as 3/11 throughout the report). The situation is still far from having been stabilized.

Overview of Onsite and Offsite Challenges

Onsite Challenges

Spent Fuel Removal. All spent fuel from the pool of Unit 3 had been removed by February 2021. Preparatory work is still underway on Units 1 and 2, with removal further delayed, now to begin in FY 2027–2028 and to be completed by the end of 2031, more than 20 years after the disaster began.

Fuel Debris Removal. Due to technical challenges, operations have been postponed several times. An investigation into the state of the structure supporting the reactor pressure vessel of Unit 1 raises concerns about its potential collapse, as much of the concrete around the rebars has apparently melted.

Contaminated Water Management. As water injection continues to cool the fuel debris, highly contaminated water has continued to run out of the cracked containments into the basements mix with water from an underground river that has penetrated the basements. The combination of various measures have reduced the influx of water from up to 540 m^3/day to about 90 m^3/day. Every day, an equivalent amount of water is partially decontaminated and stored in 1,000-m^3 tanks. Thus, a new tank is still needed almost every 10 days.

As of 24 August 2023, about 1.3 million m^3 of treated water were stored in 1,046 tanks.

The safety authority agreed to operator TEPCO's plan to release the contaminated water into the ocean. As of the end of March 2023, about two thirds of the water must be treated again, and the water diluted by a factor of 100 (or more) before it is released into the ocean through a one-kilometer-long sub-seabed tunnel. Release of the first batch of partially decontaminated water began on 24 August 2023. The operation will take at least three decades. The plan remains widely contested, including overseas.

Offsite Challenges

Offsite, the future of tens of thousands of evacuees, food contamination, and the management of decontamination wastes, all remain major challenges.

Evacuees. As of 1 May 2023, about 27,000 residents of Fukushima Prefecture were still living as evacuees, down from a peak of nearly 165,000 in May 2012. In 2022, evacuation orders for some parts of the so-called "difficult to return areas" were lifted for the first time; these areas continue to have significant exposure levels and are designated as "reconstruction and revitalization areas". The rate of return varies greatly from 1 percent to 90 percent.

Food Contamination. According to official statistics, of a total of 36,309 samples that were analyzed in financial year 2022, 135 from ten prefectures exceeded the radionuclide concentration limit. Whether the testing program provides an adequate picture of the situation remains open. As of 1 July 2023, 12 countries and regions—down from a peak of 54—still had import restrictions for Japanese food items in place. In July 2023, the European Commission lifted its remaining import restrictions for the E.U.

Decontamination and Contaminated Soil Management. The contaminated soil in the temporary storage area in Fukushima Prefecture is currently being transferred to intermediate storage facilities in eight areas. As of the end of March 2023, four out of a total of ten storage facilities were filled to maximum capacity, and about 88 percent of total storage capacity was filled with contaminated soil. The government is legally responsible for the final disposal of the contaminated soil.

DECOMMISSIONING STATUS REPORT

As more and more nuclear facilities either reach the end of their pre-determined operational lifetime, or close due to deteriorating economic conditions, timely decommissioning is becoming a key challenge (note that the status of radioactive waste management is not part of this analysis).

- As of mid-2023, the number of closed power reactors reached 212 units—eight more than one year earlier. Thus, almost one third of the reactors connected to the grid in the past 70 years have been closed. These had a total operating capacity of 105 GW, exceeding 100 GW for the first time.
- 190 units are awaiting or are in various stages of decommissioning, eight more than one year earlier.
- Only 22 units, or 10 percent of the closed reactors, have been fully decommissioned, no change over the past year: 17 in the U.S., four in Germany, and one in Japan. Of these, only 11—one more than in WNISR2022—or 5 percent of all closed reactors have been released from regulatory oversight.

- The average duration of the decommissioning process is about 21 years, with a large range of 6–45 years (both extremes are for reactors with very low power ratings of respectively 22 MW and 63 MW).
- The analysis of 11 major nuclear countries hosting 84 percent of all closed reactors shows that progress in decommissioning remains slow: of 159 units in various stages of advancement, six are in the post-operational phase, 75 are in the "warm-up stage", 27 are in the "hot-zone stage", 12 are in the "ease-off stage", while 39 are in "long-term enclosure".
- To date, none of these early nuclear states—U.K., France, Russia, and Canada—has fully decommissioned a single reactor.

POTENTIAL NEWCOMER COUNTRIES

Three potential newcomer countries had nuclear reactors under construction as of mid-2023: Bangladesh, Egypt, and Turkey. All these projects are implemented by the Russian nuclear industry. The impact of sanctions and potential other geopolitical developments on the future of these projects remains uncertain albeit some effects have already been documented.

Other countries like Kazakhstan, Nigeria, Saudi Arabia, and Uzbekistan have more or less advanced plans, but so far none of them has selected a design nor raised necessary financing. Several countries, including Indonesia, Jordan, Thailand, and Vietnam have suspended or cancelled earlier plans. Some key developments:

Bangladesh. Two reactors of Russian design have been under construction since 2017–2018. They were scheduled to start up in 2023 and 2024. Reportedly, sanctions have led to delays in the delivery of some equipment and the commissioning of Unit 1 has been pushed back to late 2024 at least.

Egypt. Construction of the first, Russian-designed nuclear power plant was launched at the El-Dabaa site on 20 July 2022, even as the war in Ukraine was ongoing. Building of Units 2 and 3 began in November 2022 and May 2023 respectively.

Kazakhstan. Several potential suppliers had been considered for the construction of small or large reactors, but no technology has been chosen, no site selected, and no financing package announced.

Nigeria. The country signed nuclear cooperation agreements with several countries and considered the option of developing up to 4 GW of nuclear capacity. However, when in early 2023 Nigeria launched its Energy Transition Plan (ETP) with the goal of carbon neutrality by 2060, nuclear power did not feature amongst the options outlined for electricity generation.

Saudi Arabia. In early 2023, the government confirmed it had received bids from China, France, Russia, and South Korea for the construction of two large reactors.

Turkey. Construction of four units started between 2018 and 2022 at the Akkuyu site. Construction on Unit 4 started in July 2022. Turkish authorities had hoped to connect Unit 1 to the grid in 2023, to coincide with the 100th anniversary of the foundation of the Republic of Turkey. That target was missed, and startup of the first unit is now expected in 2024, and commercial operation in 2025.

Uzbekistan. In May 2022, officials announced that a site for the construction of two Russian-designed VVER-1200 reactors had been chosen in the Farish district of the Jizzakh region, near Lake Tuzkan. The financing package had been under negotiations then and no further information was released.

SMALL MODULAR REACTORS (SMRs)

Just as in previous WNISR editions, this year's update on the development status and prospects of Small Modular Reactors (SMRs) does not reveal any major advances despite increasing media attention and additional public funding commitments. The country-by-country status:

Argentina. The CAREM-25 project has been under construction since 2014. Following numerous delays, the current estimated date for startup remains 2027. An updated cost estimate has not been released, but the last released one—predating the latest delays—suggests that on a per kilowatt basis CAREM-25 will cost roughly twice as much as the most expensive Generation-III reactors.

Canada. Strong federal and provincial government support for the promotion of SMRs continues. The largest commitment, of over US$$_{2022}$745 million, came from the Federal Infrastructure Bank for an SMR project at the Darlington site. Several designs have gone through a "pre-licensing vendor design review" none has yet been certified by the safety authority.

China. It took ten years between construction start and first full power in December 2022 for two high-temperature reactor modules, twice as long as anticipated. Since then, the operational record has been apparently disappointing. Construction started on a second design, the ACP100 or Linglong One, in July 2021. This is six years later than planned, with scheduled startup now by February 2026.

France. In February 2022, President Macron announced a US$$_{2022}$1.1 billion contribution to finance the development of the Nuward SMR design and other "innovative reactors". Currently, "basic design" studies are to be completed by 2026 and construction is scheduled to start in 2030.

India. An Advanced Heavy Water Reactor (AHWR) design has been under development since the 1990s, but its construction has been continuously delayed. There have been no signs that construction could start any time soon. There have been reports about plans for "a roadmap for studying the feasibility and effectiveness" of SMRs.

Russia. Russia operates two SMRs on a barge called the Akademik Lomonosov. Both reactors were connected to the grid in December 2019, nine years later than planned. Since then, their performance has been mediocre. Construction on a second SMR project, a lead-cooled fast reactor design called BREST-300, started in June 2021. The project has been discussed for a decade and was originally to be deployed by 2018.

South Korea. In 2012, the System-Integrated Modular Advanced Reactor (SMART) design received approval by the safety authority, but there have been no orders since. Several other designs are reportedly in very early stages of development. Foreign SMR developers have started proposing their competing designs in the country, but without tangible success beyond symbolic Memoranda of Understanding.

United Kingdom. Since 2014, Rolls-Royce has been developing the "UK SMR", a (now) 470 MW reactor (exceeding the size-limit of 300 MW for the generally adopted SMR definition). The regulator is currently carrying out a Generic Design Assessment (GDA) that is scheduled to be completed by August 2026. Six other SMR designs are under review. The U.K. government is aiming for a Final Investment Decision by 2029.

United States. The Department of Energy (DOE) has already spent more than US$1.2 billion on SMRs and has announced further awards over the next decade that could amount to an additional US$5.5 billion. However, there is still not a single reactor under construction. Only one design, NuScale, has received a (conditional) final safety evaluation report. However, since then, the design capacity has been increased from 50 MW to 77 MW per module, and many issues remain unsolved. In October 2021, eight municipalities withdrew from the only investment project, in the Western states, leaving the 6-module 462 MW project with subscriptions amounting to just 101 MW. By January 2023, cost estimates had ballooned to US$9.3 billion, and in early November 2023, the entire project was terminated, officially because "it appears unlikely that the project will have enough subscription to continue toward deployment".

NUCLEAR ECONOMICS AND FINANCE

Overview

Nuclear power plant projects are amongst the most expensive construction projects of any kind. Some of the main selling points of nuclear—a firm rather than variable power source (although that is questionable in light of recent performances e.g. in Belgium, France, and Japan), low-carbon, dispatchable, and generating heat that can be used for other purposes—are all attributes that are under pressure from a wide range of other, increasingly innovative options throughout the system. These innovative pressures are not limited to generation but extend to all attributes affecting the cost and reliability of the service as well—for example, efficient use or demand response, electric-vehicle-to-grid integration, or power storage to address the variable nature of wind and solar generation. Already some models show that solar photovoltaics (PV) plus storage can have load factors of 50–70 percent. Long-term contracts pairing solar, wind, and storage are already being struck.

In Key Markets, Nuclear Finance Driven by Geopolitics, Not Economics

While a reliable comprehensive, global overview of credit data is not available, partial data indicates strong credit support especially from Russia and China for overseas projects. "Lavish financing" conditions are key to the relative success of both countries. According to a former Nuclear Energy Agency (OECD-NEA) official, "privately-owned equity companies in the nuclear sector are no longer competitive in international markets" and "China and Russia are in the process of putting the West's nuclear industry out of business". China's investments beyond Hinkley Point C in the U.K. are slated to ramp up quickly, with 30 reactor projects abroad by 2030 and an associated investment of more than US$145 billion. How many of these projects will come to fruition is highly uncertain, especially considering U.S. government blacklisting of the main Chinese nuclear companies. However, there seems to be a trend towards an increasing role for Export-Import Banks and various international development banks to finance nuclear projects. The U.S. EXIM Bank has issued letters of interest in multi-billion-dollar financing of newbuild projects in Poland, Romania, and Ukraine. State intervention has been increasing in many countries for some time. WNISR estimates that already roughly 45 percent of global nuclear capacity is fully state-owned.

Operating Reactors Face Continued Competitive Pressure, Receive State Support

In recent years, operating reactors have been facing financial challenges in many countries. Unplanned outages have cut into output, and aging reactors or unexpected problems have sharply driven up plant repair and reinvestment costs, particularly in France and Japan. Plant performance has also suffered from climate-related impacts, such as cooling water availability, heat sink capacity, and storm events. While the effect on overall output remains limited until now, climate-related disruptions of nuclear generation have increased eight-fold over the past 30 years and can have significant impact on available capacity for limited periods of time. Competition by low-cost natural gas, and increasingly wind and solar, represents serious competitive risks for nuclear, especially during certain periods of the year or times of day. For example, in Finland, surging renewables production and negative wholesale power prices forced curtailment of generation at the much-delayed Olkiluoto-3 plant, a month after it commenced commercial operation. Similar cuts have been made at Spanish reactors. In the U.S., 13 reactors officially closed between 2013 and 2022 (including three reactors that had ceased electricity production in 2009 and 2012). Cost pressures are most evident in competitive power markets.

Arguing that plant closures would drive up carbon emissions and that their product, labelled "low-carbon, reliable power", was not being properly valued by the market, the industry has tagged the closures as premature, and has lobbied for—and increasingly often successfully obtained—large subsidies to support operating uneconomical plants. In the U.S., state-level taxpayer-funded subsidies were granted to 19 reactors; these last from five to 12 years and are estimated to exceed US$15 billion by 2030. Federal subsidies called Zero-Emission Nuclear Production Credits offer a maximum of US$15/MWh for plants operating from 2024 to 2032. They can likely be combined with other subsidies, e.g. for hydrogen production. In addition, the Civil Nuclear Credit (CNC) program funded a national pool of US$6 billion in subsidies to keep economically distressed reactors from closing.

The largest nuclear operator in the world, the French utility EDF, has been fully renationalized. The French government is also lobbying to allow the possibility of accessing various E.U. financing mechanisms to subsidize its existing nuclear fleet. In Belgium, the government has agreed in principle to share the economic risk of a planned 10-year lifetime extension of two reactors beyond the previously agreed closure date of 2025 by setting up a joint company with utility Engie-Electrabel. Japan has de facto nationalized the Fukushima operator TEPCO injecting unlimited funding for compensation of victims and disaster remediation. In order to expedite the restart of reactors shuttered since 3/11, the Japanese government is also considering subsidies that would guarantee income to winning bidders for the subsequent 20 years. This would be an extension of the "long-term decarbonized power supply auction," slated to begin in early 2024.

Economics of New Reactors in the Context of Government Support

The OECD-Nuclear Energy Agency's overnight cost (excl. financing and other costs) estimates for Light Water Reactors (LWR) vary by a factor of two from US$$_{2018}$2,157 per installed kilowatt (South Korea) to US$$_{2018}$4,250/kW (U.S.). An independent assessment from the Workgroup for Infrastructure Policy (WIP, at Technical University Berlin) and the German Institute for Economic Research (DIW) based on an 88-reactor database found much higher values, including about US$6,000/kW for mean overnight costs for LWRs.

Overnight cost analyses have some significant limitations for the assessment of nuclear competitiveness: the exclusion of financing and other costs, although financing is frequently recognized as a key component; the very limited number of real cases to serve as reference; the frequent assumption for *n*th of a kind implementation supposing learning effects through the building of a series of units, but without clearly defining the number *n*, which can range from five to hundreds (in the case of SMRs). However, the production scales of nuclear's main competitors are in entirely different orders of magnitude. The installed base of wind turbines is more than 300,000 globally, with more than 25,000 installed in 2022 alone. Solar PV module (each panel has multiple modules) production translates to a unit count in the hundreds of millions per year, with well-documented associated learning effects and cost reductions.

An academic analysis of delays and cost overruns of "megaprojects", leady by Bent Flyvbjerg, found that nuclear waste projects top of the list with mean cost overruns of 238 percent, and nuclear power plants rank third with mean cost overruns of 120 percent.

The most advanced SMR design in the U.S., NuScale, terminated a six-module project to be implemented for a conglomerate of Utah municipalities, in early November 2023. Cost estimates had spiked to US$20,000/kW. Despite massive federal subsidies estimated to exceed US$4 billion, the projected cost of electricity appeared too high for most candidate municipalities.

Trends in Nuclear LCOE Estimates

Levelized Cost of Energy (LCOE) assessments incorporate not only construction expenses (so-called overnight costs) but also operating and maintenance costs, build times, load factors, and discount rates to generate an average cost per unit energy produced over the plant's lifetime. Values here have been scaled to 2018 US$. Analysis by the OECD's International Energy Agency (IEA) and their Nuclear Energy Agency (NEA) highlights the sensitivity of applied discount rates to nuclear LCOEs. While there are no pure market-based benchmarks for nuclear cost-of-capital, historical cost overruns and delays suggest rates should be higher than for energy pathways with more predictable build costs. As discount rates rise, nuclear becomes less and less competitive with other energy policy options.

Further, nuclear LCOE estimates span a wide range even when the same discount rate is assumed. Analysis of IEA's Electricity Survey estimates mean LCOEs range from US$51/MWh in non-OECD countries to US$62/MWh at a 5 percent discount rate. This is far below the mean nuclear LCOE of U$100/MWh in an independent meta-analysis (including the IEA datasets) of 88 planned and completed nuclear projects (WIP/DIW). IEA's Net Zero assessments indicate a range from US$102/MWh in the U.S. to US$145/MWh in the E.U. at 8 percent discount, with the World Energy Outlook indicating a range from US$87/MWh in the U.S. to US$129/MWh in the E.U. at the same discount rate.

Asset-management firm Lazard concluded from similar analysis that aside from natural gas peaking plants at discount rates of less than 5.4 percent, nuclear turned out always the most expensive resource on an LCOE basis. At a 7.7 percent discount rate, nuclear came out at US$158/MWh. At a discount rate of 10 percent, and excluding firming costs, nuclear is nearly four times the LCOE of onshore wind.

LCOE estimates for non-OECD countries tend to be lower than that within OECD countries, though based on more limited data. Given the large role of these countries in newbuild projects, improved data access would be very helpful.

Missing and Underestimated Costs

Beyond the nuclear generating station, there are ancillary requirements of the nuclear fuel chain that are more expensive and more complex than for most other forms of energy generation. These other elements are not always well-captured in the economic evaluations of the resource, and explicitly excluded in some assessments. Key questions are whether decommissioning—not only of the power plant but also of the fuel chain facilities—as well as waste management costs are included in the cost assessments; and, if so, whether those assessments are comprehensive. Earmarked funds need to be of appropriate scale and prudently invested to meet needed targets when needed. Unfortunately, adequate funds are often not collected during the full operation of the facility. In other cases, collected funds have been misappropriated due to structural weaknesses in controls.

Decommissioning cost estimates vary widely, and empirical data area limited. In the U.S., reactor decommissioning estimates span a range of US$478–1,435/kWe for publicly-owned reactors and US$615–2,148/kWe for investor-owned reactors.[10] The reasons behind the much higher cost projections for investor-owned utilities are not clear.

A detailed reactor-level WNISR analysis estimated decommissioning costs for the three nuclear phaseout countries Germany, Italy, and Lithuania at approximately $US\$_{2020}$6.8, $US\$_{2020}$16 and $US\$_{2020}$15.7 per MWh, respectively, for high-capacity commercial reactors—at least an order of magnitude larger than most international estimates and at a level that could affect the competitiveness of nuclear, especially on wholesale markets. These cases are particularly

10 - Callan Institute, "2022 Nuclear Decommissioning Funding Study", December 2022, pp. 5–6, see https://www.callan.com/research/2022-nuclear-decommissioning-study/, accessed 7 July 2023.

significant as the total generation of nuclear electricity is known and thus allow to allocate costs to a fix number of kWh.

An IAEA analysis on funding mechanisms of decommissioning and waste management costs found that about 30 percent of the countries rely on government funding or that of a state-owned enterprise. For the other 70 percent, coverage security is uncertain. All countries rely on taxpayer money to make up for shortfalls.

Detailed European case studies highlighted large aggregate shortfalls between provisioned funds for decommissioning and the expected costs. This gap amounted to estimated $US\$_{2023}$10.9 billion in France, $US\$_{2023}$6.6 billion in Germany and $US\$_{2023}$2.7 billion in Sweden. In the U.S., the transfer of ownership of closed reactors—together with their access to decommissioning funds—to private companies carries specific risks in the case of cost overruns, bankruptcy, or a major accident that could rapidly drain available funding.

Cost estimates for nuclear waste management from the operation of reactors and fuel chain facilities as well as from their decommissioning have reached astronomical levels. For spent fuel disposal alone, estimates for the U.S. reach up to $US\$_{2018}$168 billion and for Canada over $US\$_{2020}$19 billion; for the French high-level waste repository construction, there is a "target cost" of $US\$_{2016}$28 billion; and if including all radioactive waste streams, estimated disposal costs reach $US\$_{2023}$163 billion for Germany; and $US\$_{2021}$21 billion for Switzerland.

Nuclear waste management costs per kWh for SMRs are likely to be higher still than in the case of large reactors.

Insufficient Liability Coverage for Nuclear Accidents

Inadequate or subsidized insurance to cover offsite damages from accidents at nuclear power plants or fuel chain facilities, or during transportation, is common worldwide. Focusing on reactor accidents as an example, liability requirements for offsite damages are set by domestic statute. Additional tiers may be provided by national governments once the operator liability limit is reached; and then by a third tier of coverage provided by series of international treaty agreements (which include the Paris Convention, Vienna Convention, various Joint Protocols and Supplementary Conventions). However, even the total coverage in the U.S., which is the largest liability pool in the world for nuclear accidents, is well below expected damages from even a moderate accident. For example, the Japanese Government estimated the cost of the 2011 Fukushima accidents at $US\$_{2021}$223 billion, more than sixteen times the total U.S. insurance pool of US$13.6 billion. The size of the pool declines as older reactors close. Smaller reactors such as SMRs have much lower primary limit requirements via the mandated purchase of a reactor-specific insurance policy. These depend on the size of the reactor but cover a damage range of only US$4.5–74 million. Further, if the reactors are smaller than 100 MWe, they need not participate in the retrospective premium pool at all.

Industry Claims Regarding Uncompensated Benefits, Future New Markets

Industry proponents sometimes claim there is inadequate compensation for nuclear's role as a provider of firm and high-capacity low-carbon electricity that is also dispatchable. Capacity payments already compensate providers for firm, high-capacity generation in many U.S. power markets and increasingly in Europe as well. Carbon pricing in the E.U.'s emissions trading system, and to a lesser extent some parts of the U.S., already benefit nuclear providers relative to their fossil competitors. The case for dispatch remains unproven, as the sector's ability to ramp power production to boost supply flexibility remains limited technically, and associated reductions in load factors needed to spread high fixed costs counter incentives to curtail the resource.

Emerging market services that are supposed to help make the economics of nuclear work include hydrogen production, water desalination, supplying industries in need of high temperature process heat, and behind-the-perimeter uses such as data centers and crypto mining. Because most of these uses involve capital-intensive customers relying on nearly 24/7 production to be economic, a nuclear supplier would need to allocate a fixed percentage of production to that user rather than selling intermittent power surpluses. Thus, the alternative markets would compete with existing power customers, not supplement them. Should some use configurations (for example for low-carbon nuclear used to produce hydrogen) be able to stack multiple subsidies on top of each other, nuclear diversions from power markets could rise, as potentially would carbon emissions. Expansion of the reactor base through newbuild would address concerns regarding diversion of existing low-carbon power supply. However, the costs of power are widely viewed as too expensive relative to alternatives to support these ancillary markets.

Chapter Conclusion

Overall, the economic headwinds for nuclear will remain challenging. Research and deployments will rely primarily on government money, absorption of risks, and direct ownership. Even "private" reactor projects will operate in heavily government-supported environments. In the broader energy marketplace, it is likely that by the time cost improvements could occur, technological developments in competing generating technologies, energy storage, demand side management, and energy efficiency will have moved the economic costs down still further and the reactors will remain too costly. No-regrets policies such as putting an appropriate price on carbon would help nuclear economics as well as other decarbonization pathways, though in a more market-neutral way than most of the current "policy support".

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

Events in Ukraine, which roiled energy markets in 2022, continue to have significant effects on energy-policy decisions for the short and medium term. Some countries have clearly boosted their investments in renewable energies but nuclear power has remained high on the political agendas even though little has followed on the ground so far.

Investment. In 2022, total investment in non-hydro renewable electricity capacity reached a new record of US$495 billion, up 35 percent compared to the previous year, and 14 times the reported global investment decisions for the construction of nuclear power plants of about US$35 billion for 9.4 GW. Investment in solar surged by 50 percent to reach US$307 billion following a 37 percent increase in 2021. Investments in wind power plants increased by 19 percent to US$174 billion. Investments in renewables constitute an estimated 74 percent of all power generation investments in 2022: in contrast, investment in nuclear energy accounted to only 8 percent, the same level as for new coal plants. China's renewables investment was more than a factor of two larger than the combined European and U.S. investments and larger by than the total global investment in nuclear power over the past decade.

Installed Capacity. A record 348 GW of new renewable energy capacity (including hydro) was installed in 2022, with wind adding around 75 GW of new capacity. The estimates of new solar PV capacity vary widely from 191 GW (IRENA) to 243 GW (REN21) taking total installed capacity beyond 1 terawatt for the first time (in both estimates). These numbers compare with a net addition of 4.3 GW in operating nuclear power capacity.

Electricity Generation. In 2021, the combined output of solar and wind plants surpassed nuclear power generation for the first time. In 2022, wind and solar facilities generated 28 percent more electricity than nuclear plants. Load factors have improved significantly and, as of 2020, stood at 16 percent for utility scale PV, 36 percent for onshore wind, and 44 percent for offshore wind. A floating offshore Scottish wind farm has achieved an *average* load factor of 54 percent over its first five years of operation, higher than the 52 percent for the French nuclear fleet in 2022.

Share in Power Mix. In 2022, wind (7.2 percent) and solar (4.5 percent) together reached 11.7 percent share of electricity generation, with all non-hydro renewables increasing to 14.4 percent, while the contribution of nuclear energy declined to 9.2 percent.

China. Solar PV produced a total of 423 TWh of electricity in 2022, for the first time overtaking nuclear power that generated 397 TWh. Wind outpaced nuclear in 2012 and has stayed ahead every year since. Wind power plants produced 755 TWh, nearing the double of nuclear power generation. Adding other non-hydro renewables like biomass to solar and wind, total generation of 1,346 TWh net represents 3.4 times the nuclear output, or more than twice the total consumption (577 TWh gross) of Germany, the world's third largest economy.

European Union. In 2022, renewable electricity generation (including hydropower) reached a new record of 1,080 TWh (gross), with solar energy contributing 203 TWh, up 24 percent from the previous year. Solar and wind plants together produced 624 TWh—more than nuclear energy with 613 TWh, natural gas with 557 TWh, and coal with 447 TWh. All renewable sources combined accounted for over 38 percent of the E.U.'s electricity production.

India. During 2022, 13 GW of solar power capacity was added to reach a total of 62.8 GW. Solar PV generated 94.2 TWh during the year. Since 2021, solar plants have generated more power than wind turbines, which contributed 69 TWh in 2022. Wind has outpaced nuclear in power generation since 2016. Solar passed nuclear generation in 2019. Wind and solar together produced 3.7 times more power than nuclear plants in 2022.

United States. In 2022, nuclear generation declined by 4.7 percent to 772 TWh or 18.2 percent of the electricity mix while wind and solar energies together contributed 14 percent. Including other power sources like biomass and geothermal, non-hydro renewables generated 709.4 TWh (net). If hydropower plants are included contributing 256 TWh, for the first time, with 965.4 TWh, renewables generated more power than coal with 904 TWh (gross).

INTRODUCTION

2023 is not over yet, but it is obvious that the war in Ukraine will not have ceased at year-end. Another brutal war has started in the Middle East with protagonists already warning that it will be a long one. Countless scenarios for a regional escalation are possible. And, if Hamas missiles went all the way to Tel Aviv, the Israeli military nuclear complex Dimona in the Negev desert is clearly within reach.

Ukrainian nuclear power plants remain in the middle of an active war zone with one site, the Zaporizhizhia nuclear plant, still occupied by Russian military forces, assisted by engineers of Russian state-owned company Rosatom. As long as the war goes on in Ukraine, there remains a significantly heightened risk of a major nuclear disaster. WNISR2022 detailed why a nuclear reactor needs a functioning cooling system at all times, meaning it also needs reliable electricity supply at all times—during operation and after shutdown.

Repeated calls by various stakeholders, including the Ukrainian Government and the European Parliament, to extend sanctions against Russia to the nuclear sector have remained largely unheeded, aside of U.S. sanctions against Rosatom subsidiary Rusatom Overseas that used to implement Rosatom projects in various countries. Interestingly, that April 2023 decision did not trigger any mainstream media coverage at all, apart from a piece in the French satirical journal *Le Canard Enchaîné* in August 2023.[11]

Dependencies of many countries on Russia as nuclear service and hardware provider remain deep. In the European Union (E.U.), Bulgaria, the Czech Republic, Finland, Hungary, and Slovakia operate Russian designed VVERs and are depending on Russian fuel to a great extent. Westinghouse, besides Rosatom the only manufacturer able to manufacture fuel assemblies for the Soviet designed reactors, has so far supplied VVER fuel mainly to Ukraine. These fuel supplies were so far limited to VVER-1000 reactors and have had technical difficulties, but Westinghouse reported in September 2023 to have delivered the first batch of VVER-440 fuel, fabricated in its Swedish plant in Västerås. This will be used in Ukraine for the two-unit Rivne (Rovno) nuclear power plant.[12] Ukraine's Minister of Energy German Galushchenko commented:

> The greatness of this day is the end of the Russian monopoly in this segment of the nuclear fuel market. This will pave the way for not only Ukraine, but the whole region, to achieve true nuclear energy independence.

This development is indeed of great significance also to four E.U. countries that operate VVER-440 reactors in the E.U.[13] VVER operators have shown interest in Westinghouse fuel in the past and that interest has obviously significantly grown since February 2022. However, following the signature of a "Strategic Cooperation Agreement" with Rosatom in December 2021, French manufacturer Framatome continues to count on its Russian partner

11 - *Le Canard Enchaîné,* "Les Américains veulent atomiser le nucléaire franco-russe", 30 August 2023.

12 - Westinghouse, "Westinghouse Delivers First VVER-440 Fuel Assemblies to Energoatom", Press Release, see https://info.westinghousenuclear.com/news/westinghouse-delivers-first-vver-440-fuel-assemblies-to-energoatom, accessed 22 November 2023.

13 - Bulgaria and the Czech Republic operate two VVER-1000 each, the VVER-400 are in Finland (2), Hungary (4), the Czech Republic (4) and Slovakia (5).

and wishes to manufacture VVER fuel in its manufacturing plant in Lingen, Germany, and market the fuel through a Rosatom/Framatome Joint Venture. Why Framatome did not seek cooperation with Westinghouse—whose President and CEO is a French national—rather than cooperate with Rosatom remains unclear. Framatome and Westinghouse cooperate in other areas of nuclear power (e.g. emergency diesel generators, maintenance, Cobal-60 production). Obviously though, the region remains far from "true nuclear energy independence".

Despite the war in Ukraine, Russia continues to enjoy the top spot in the niche sellers' market of nuclear reactor building around the world. Since the official construction start of the second Hinkley Point C unit in the U.K. in December 2019 and until mid-2023, work began on 28 reactors in the world, of which 17 in China and all 11 others implemented by Rosatom in various countries. Since Russia's full-scale invasion of Ukraine in February 2022 and up to mid-2023, Rosatom started building three reactors in Egypt, and one each in China and Turkey.

The question about the role of the International Atomic Energy Agency (IAEA) had been raised in the Introduction to WNISR2022. The Agency's Director General Rafael Mariano Grossi repeatedly visited the Ukrainian nuclear sites and confirmed Rosatom's presence in Zaporizhizha. Meanwhile, Mikhail Chudakov, appointed by President Putin and former longtime official of Rosatom companies, remains Grossi's Deputy Director General and Head of the IAEA's Department of Nuclear Energy.

Two IAEA General Assemblies passed since the beginning of the all-out war in Ukraine, and not a word has come out of the meetings on potential discussions about basic conditions for technical assistance now and in the future. Russia remains the country that implements by far the most newbuild projects around the world, of which many, if not all, with the assistance of the IAEA. It remains unclear under what conditions Russia, state-owned Rosatom, and its many subsidiaries can be seen as responsible nuclear partners now and in the future—or rather, how the general, applicable, non-negotiable IAEA conditions for nuclear assistance and cooperation would be defined. Neither political decision-makers nor the international media have addressed the issue.

The international media continues to provide large-scale coverage of early, often vague developments of Small Modular Reactor (SMR) designs, despite no significant progress on the ground to report—at least not outside China and Russia—with no startups, no construction starts, not even a design certification. On the contrary, the most advanced project in the western world, the U.S.-based NuScale project with a conglomerate of Utah municipalities was terminated in early November 2023. The company NuScale lost more than 80 percent of its stock market value in little more than a year. Unmoved by the foreseeable NuScale project meltdown, the European Commission launched precisely at the same time a "European Industrial Alliance on SMRs".

The key element for the NuScale debacle was the dramatically increased cost estimate of the project to US$9.3 billion, which brought the estimated cost per kilowatt to US$20,000 for the six-module 462 MW plant, about twice the cost estimate of the most expensive European Pressurized Water Reactor (EPR).

In the chapter Nuclear Economics and Finance, WNISR2023 assesses in great detail the various cost elements of nuclear power and why the economic headwinds for nuclear will remain challenging. Competing generating technologies, energy storage, demand side management, and energy efficiency will continue to move the economic costs down still further and the reactors will remain too costly to compete. The latest Goldman-Sachs analysis provides only the latest example of many. It forecasts that costs for batteries used in electric vehicles will fall by 40 percent between 2022 and 2025 to US$99/kWh and an average of 11 percent per year until 2030.[14] Already dozens of natural gas plant projects are being shelved around the world in favor of large grid-connected batteries.

The 2023-United Nations Environment Program (UNEP) Emissions Gap Report[15] demonstrates the extent to which current Greenhouse gas emissions trajectories will overshoot the temperature guidelines of the 2015 Paris Agreement—avoid global temperatures rising 1.5 degrees Celsius above pre-industrial levels. This, coupled with the extreme weather events that are occurring at an alarming and ever-increasing rate, and 2023 expected to be hottest year on record, are once again leading to calls for urgent international action to reduce emissions.

While action is needed across all sectors and societies, one of the highest profile initiatives is the call for a trebling of the current use of renewables and the doubling in energy efficiency by 2030. These targets, already embraced by 70 countries as of mid-November 2023, are expected to be endorsed by the global community at COP 28 taking place in December 2023. If fully implemented, they are expected to lead to three times the current level of wind power and five times the installed capacity of solar PV. This would need to be accompanied by the transformation of the power sector with priority given to measures that increase system flexibility, such as dynamic demand, energy storage, and transformed power grids moving further away from a system using centralized generators, like coal and nuclear power.

Considering the data presented in WNISR2023, a similar pledge to triple nuclear power generation by 2050—considering the long lead-times involved in nuclear construction—seems highly unrealistic and, so far, attracted relatively little support with 10 countries signing up by mid-November 2023.

There is an ever-widening gap between media attention, political announcements, public perception on one side and the industrial reality on the other side. The comprehensive documentation and analysis that WNISR2023 provides on the status and trends of the nuclear industry is a description of an economic sector that struggles to maintain ageing operating fleets, accumulates significant delays and cost overruns at construction projects, and fails to timely develop competitive new designs.

14 - Goldman Sachs, "Electric vehicle battery prices are falling faster than expected", 1 November 2023, see https://www.goldmansachs.com/intelligence/pages/electric-vehicle-battery-prices-falling.html, accessed 24 November 2023.

15 - UNEP, "Emissions Gap Report", 20 November 2023, see https://www.unep.org/resources/emissions-gap-report-2023, accessed 25 November 2023.

GENERAL OVERVIEW WORLDWIDE

ROLE OF NUCLEAR POWER

In 1970, the Treaty on the Non-Proliferation of Nuclear Weapons (commonly known as the nuclear Non-Proliferation Treaty, or NPT) entered into force. It was seen as a key tool to limit nuclear weapons programs to the five "official" nuclear weapon states China, France, Russia (then the Soviet Union), the United Kingdom, and the United States.[16] In return for not acquiring nuclear weapons capabilities, countries were guaranteed access to technology for nuclear power. Article IV of the NPT stipulates that "nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination."[17]

Russia is currently the dominating global reactor builder outside China and works closely with the International Atomic Energy Agency (IAEA), especially in potential newcomer countries. The Russian Ministry of Foreign Affairs in its introductory statement to the First Session of the Preparatory Committee for the 11th Review Conference of the Parties to the NPT in August 2023 stressed:

> Russia considers the efforts to promote the nuclear energy development central to the IAEA work. We cooperate with the Agency in implementing the initiative launched in 2017 to develop the nuclear energy infrastructure of newcomer countries. Russia is the initiator and leading donor of the IAEA International Project on Innovative Reactors and Fuel Cycles, in which 43 countries and the European Commission participate. (…)
>
> We note that all NPT-compliant countries should have access to peaceful nuclear energy without any additional conditions.[18]

As of mid-2023, 32 countries operated nuclear power programs in the world, one less (Germany) than a year earlier. Figure 1 illustrates how the spread of nuclear power throughout the world took place at a significantly slower pace and smaller scope than anticipated in the early 1970s:

- Fourteen countries had operating nuclear power reactors (grid connected) when the NPT entered into force in 1970.
- Sixteen additional countries were operating power plants by 1985, the year when reactor startups peaked.
- Four countries (Romania, Iran, the United Arab Emirates and Belarus) started up power reactors for the first time over the past 30 years, of which two in 2020.

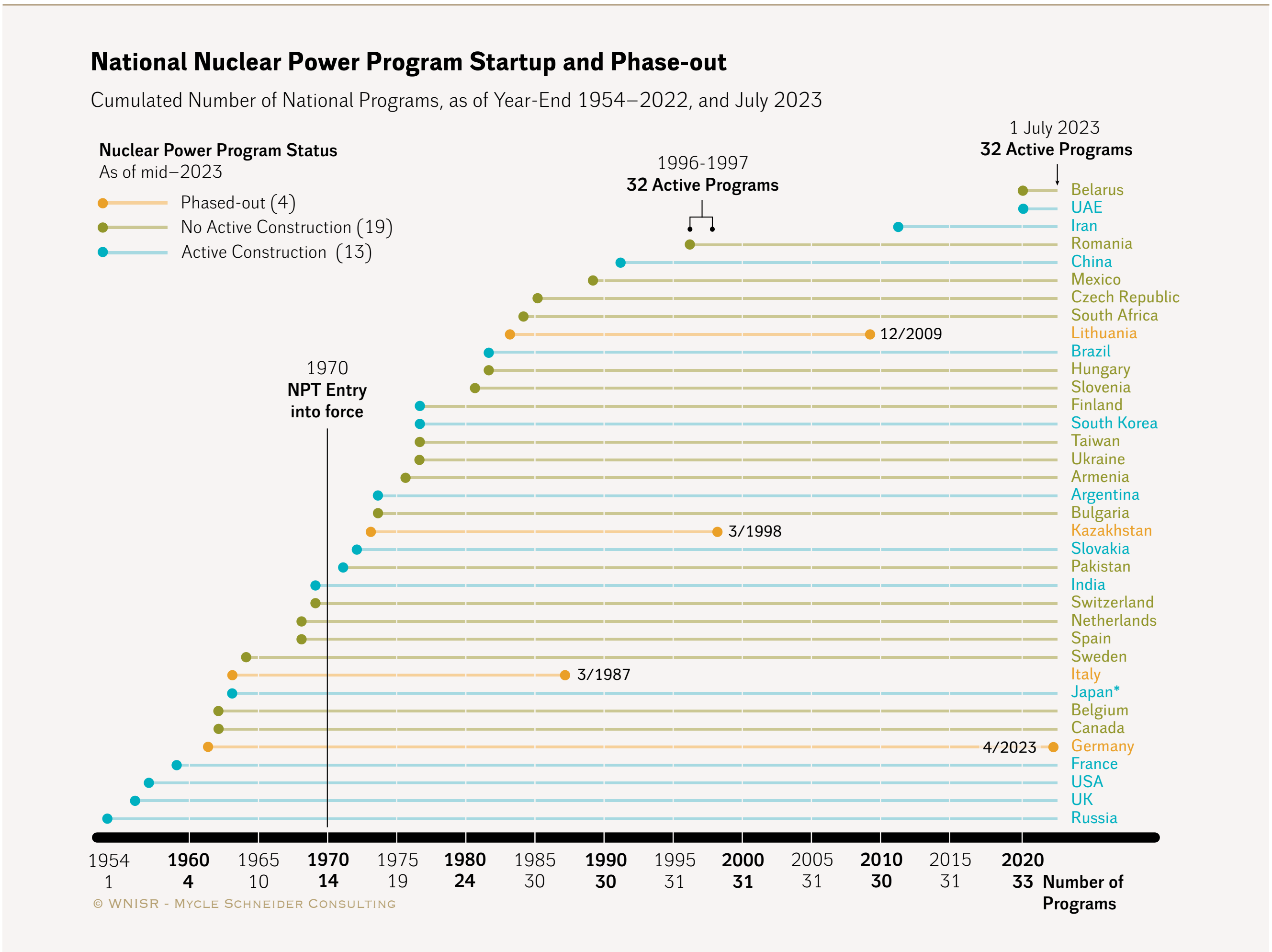
16 - Four additional countries have since acquired explosive nuclear devices (Israel, India, North Korea, and Pakistan). South Africa developed and manufactured nuclear weapons but has dismantled its program. For an overview see IPFM, "Global Fissile Material Report 2022—Fifty Years of the Nuclear Non-Proliferation Treaty: Nuclear Weapons, Fissile Materials, and Nuclear Energy", 29 July 2022, see https://fissilematerials.org/publications/2022/07/global_fissile_material_r.html, accessed 4 September 2022.

17 - UNODA, "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)", United Nations Office for Disarmament Affairs, Undated, see https://www.un.org/disarmament/wmd/nuclear/npt/text/, accessed 4 September 2022.

18 - Russian Ministry of Foreign Affairs, "Statement by the Head of the Delegation of the Russian Federation at the First Session of the Preparatory Committee for the 11th Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons (General debate)", Government of Russia, 1 August 2023, see https://mid.ru/en/foreign_policy/news/1899782/, accessed 11 August 2023.

- The number of countries operating power reactors in 1996–1997 reached 32. It took another 23 years to reach a new peak at 33 countries.
- Four countries (Germany, Italy, Kazakhstan and Lithuania) abandoned their nuclear programs.
- Thirteen of the 32 nuclear countries have active reactor construction programs.
- Nineteen countries are not constructing any reactors currently; of these, seven countries have either nuclear phase-out, no-new-build, or no-program-extension policies in place. Some of these policies, such as in the Netherlands and Sweden, are currently being revised. However, while policy changes in some countries reopen the door for nuclear newbuild, actual work on the ground would be many years away.

Figure 1 · National Nuclear Power Programs Development, 1954–2022



Sources: compiled by WNISR, with IAEA-PRIS, 2023

Notes: This figure only displays countries with operating or once operating reactors.

* Japan is counted here among countries with "active construction"; it is however possible that the only project under active construction (Shimane-3) will be abandoned.

In 2022, the world nuclear fleet generated 2,546 net terawatt-hours (TWh or billion kilowatt-hours) of electricity[19], (see Figure 2). After a decline in 2020, nuclear production increased by 3.9 percent in 2021, but stayed just below the 2019 level, and dropped by 4 percent in 2022. China, with a 3-percent increase (compared to 11 percent in 2021), produced more nuclear electricity than France for the third year in a row, and remains in second place—behind the U.S.—of the top nuclear power generators. Outside of China, nuclear production decreased 5 percent to its lowest level since the mid-1990s.

Nuclear energy's share of global commercial gross electricity generation in 2022 dropped to 9.2 percent—the lowest value in four decades—and over 45 percent below the peak of 17.5 percent in 1996.[20]

Nuclear's main competitors, non-hydro renewables, grew their gross output by 14.7 percent and their share in global gross power generation increased by 1.6 percentage points to 14.4 percent.

In 2020, in a global economic environment depressed by the COVID-19 pandemic, fossil fuel consumption in the power sector slumped: oil by 9.7 percent, coal by 4.2 percent, and natural gas by 2.3 percent. In 2021, the trend was reversed with significant increases in oil +8.9 percent and coal +8.5 percent, while natural gas-based electricity increased by only 2.3 percent. In 2022, oil consumption for power generation remained rather stable (-0.7 percent) while coal and gas slightly increased by 1 percent.

In 2022, nuclear commercial primary energy consumption decreased by 4.7 percent while its share in global consumption slightly decreased to 4 percent; it has been around this level since 2014. In the European Union (E.U.) nuclear primary energy consumption decreased by 17 percent.

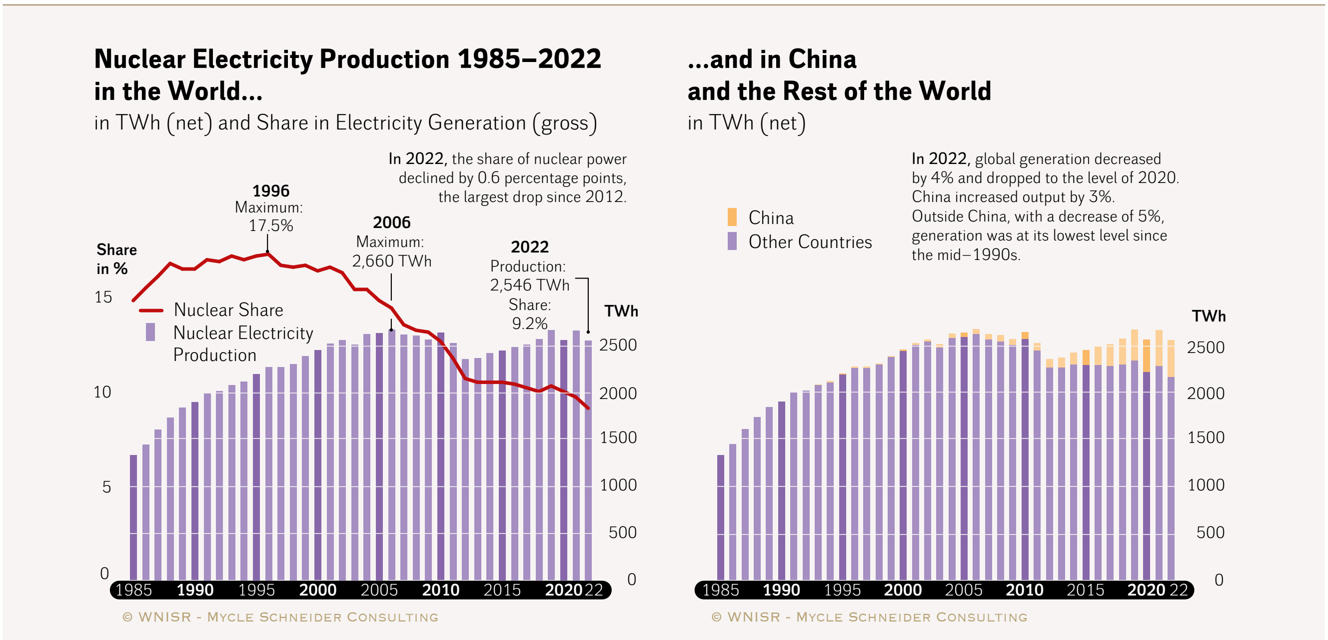
Non-hydro renewables, including mainly solar, wind and biofuels, continued their growth, with a 13 percent increase, to reach a share of 7.5 percent in primary energy. While the share of non-hydro renewables is now 1.9 times larger than the nuclear share, both figures illustrate how modest the current contribution of both technologies remains in the global context.

In 2022, there were eight countries that increased the share of nuclear in their respective electricity mix, including one newcomer country, the United Arab Emirates (UAE)—versus six in 2021—while thirteen decreased, and 12 remained at a constant level (change of less than 1 percentage point). Besides the UAE, seven countries (China, Czech Republic, Finland, India, South Korea, Pakistan, Russia) achieved their largest ever nuclear production. China, Finland, Pakistan, South Korea, and the UAE started up new reactors during the year, while the Czech Republic and Russia recorded only marginal increases (below 1 percent) and India slowly increased performance of Kakrapar-3, connected to the grid in January 2021 but in commercial operation only in June 2023.

19 - If not otherwise noted, all nuclear capacity and electricity generation figures based on International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS) online database, see https://prisweb.iaea.org/Home/Pris.asp. Production figures are net of the plant's own consumption unless otherwise noted, from IAEA-PRIS, "World Statistics—Nuclear Share of Electricity Generation in 2022", Power Reactor Information System, International Atomic Energy Agency, see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx. However, as global nuclear production for 2022 provided by IAEA-PRIS does not contain production for Ukraine, the global production of 2,546 TWh was obtained by including net production for Ukraine from Energy Institute, "Statistical Review of World Energy", 2023.

20 - This and the following paragraphs are based on Energy Institute, "Statistical Review of World Energy 2023", June 2023, see https://www.energyinst.org/__data/assets/pdf_file/0004/1055542/EI_Stat_Review_PDF_single-2.pdf, accessed 27 June 2023.

Figure 2 • Nuclear Electricity Generation in the World... and China



Sources: WNISR, with IAEA-PRIS and Energy Institute, 2023

Note: IAEA-PRIS production data for the year 2022 does not include Ukraine (data unavailable). Net nuclear production for Ukraine for the year 2022 represented 59 TWh according to the Energy Institute's "Statistical Review of World Energy" dataset.[21] The total number is thus based on IAEA-PRIS plus the production figure for Ukraine from the Energy Institute.

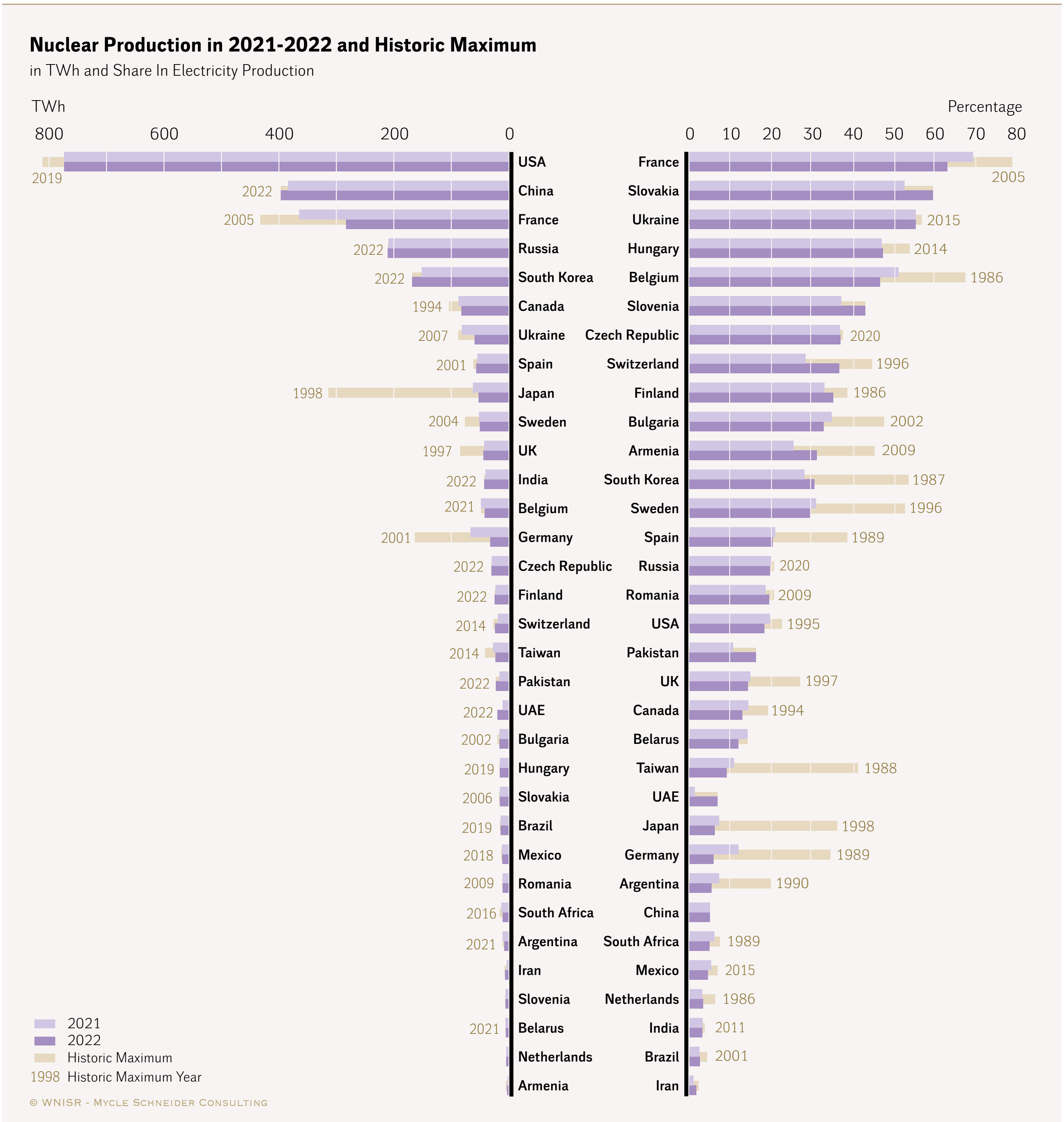
The following noteworthy developments for the year 2022 illustrate the volatile operational situation of the individual national reactor fleets (see country-specific sections for details):

- **Argentina**'s nuclear production dropped by 26.5 percent, primarily due to months-long—planned and unplanned—maintenance and reparation outages at one of its three reactors.
- **Belgium** had an exceptional 2021 after years of struggling with technical issues greatly varying nuclear power generation, only to experience a drop of 13 percent in 2022.
- **China** started up three units in 2022, just as in 2021, with nuclear generation increasing a modest 3.2 percent following an 11.2 percent in 2021.
- **France**'s nuclear generation dropped by a record 22.7 percent to below 300 GW for the first time since 1990 and remained below 400 TWh for the seventh year in a row. The outlook for 2023 remains dire with forecasted 300–330 TWh generation.
- **Germany**, subject to intense political pressure in the middle of a severe energy crisis, stretched operation of its remaining three units beyond the previously planned closure date of the end of 2022 to mid-April 2023 when the nuclear phaseout was completed.
- **Japan** has restarted ten reactors after all of them were down in 2014. In the past few years, nuclear reactors have generated greatly varying amounts of electricity. After a significant increase in 2021, production dropped again by 15.3 percent in 2022.
- **South Africa** still has a highly volatile nuclear generation pattern. In 2022, output dropped again by 17 percent contributing less than 5 percent to total power generation.

21 - Energy Institute, "Statistical Review of World Energy 2023 - Data", June 2023, see https://www.energyinst.org/__data/assets/excel_doc/0007/1055545/EI-stats-review-all-data.xlsx, accessed 27 June 2023.

→ In the **U.K.**, after decreasing steadily between 2016 and 2021, nuclear generation increased by 4.3 percent in 2022. However, the previous decreasing trend will continue as three more reactors have been closed in 2022. Consequently, output dropped 21.5 percent in the first half-year 2023 compared to the same period in 2022.

Figure 3 · Nuclear Electricity Generation and Share in National Power Generation



Sources: IAEA-PRIS, with national sources for France and Switzerland, and Energy Institute data for Ukraine, compiled by WNISR, 2023

Note: For comparison purposes, data used in this graphic are IAEA-PRIS data, except for France, Switzerland, and Ukraine, and may differ from data used in the country sections.

Similar to previous years, in 2022, the "big five" nuclear generating countries—the U.S., China, France, Russia, and South Korea, in that order—generated 72 percent of all nuclear electricity in the world (see Figure 3, left side).

In 2002, China was 15th in terms of global production levels; in 2007, it was tenth, and reached third place in 2016. In 2020—earlier than anticipated due to the mediocre performance of the French fleet—China became the second largest nuclear generator in the world, a position that France held since the early 1980s.

In 2022, the top three countries, the U.S., China, and France, remained at around 57 percent of global nuclear output, underscoring the concentration of nuclear power generation in a very small number of countries.

In many cases, even where nuclear power generation increased, the addition is not keeping pace with overall increases in electricity production, leading to a nuclear share below the respective historic maximum (see Figure 3, right side). Eight countries achieved their historically largest nuclear share in the 1980s and seven in the 1990s, in other words, almost half of the nuclear countries had seen the peak before the turn of the century.

Besides the United Arab Emirates, which started its second reactor in September 2021 and the third one in October 2022, three countries, Pakistan, Slovakia, and Slovenia, in 2022 reached new historic peak shares of nuclear in their respective power mix. Pakistan's nuclear share advanced by 4.7 percentage points to 16.4 percent, Slovakia's almost 7 percentage points to 59.2 percent, and Slovenia's 6.1 percentage points to 42.8 percent. China remained stable at 5 percent, its highest share.

OPERATION, POWER GENERATION

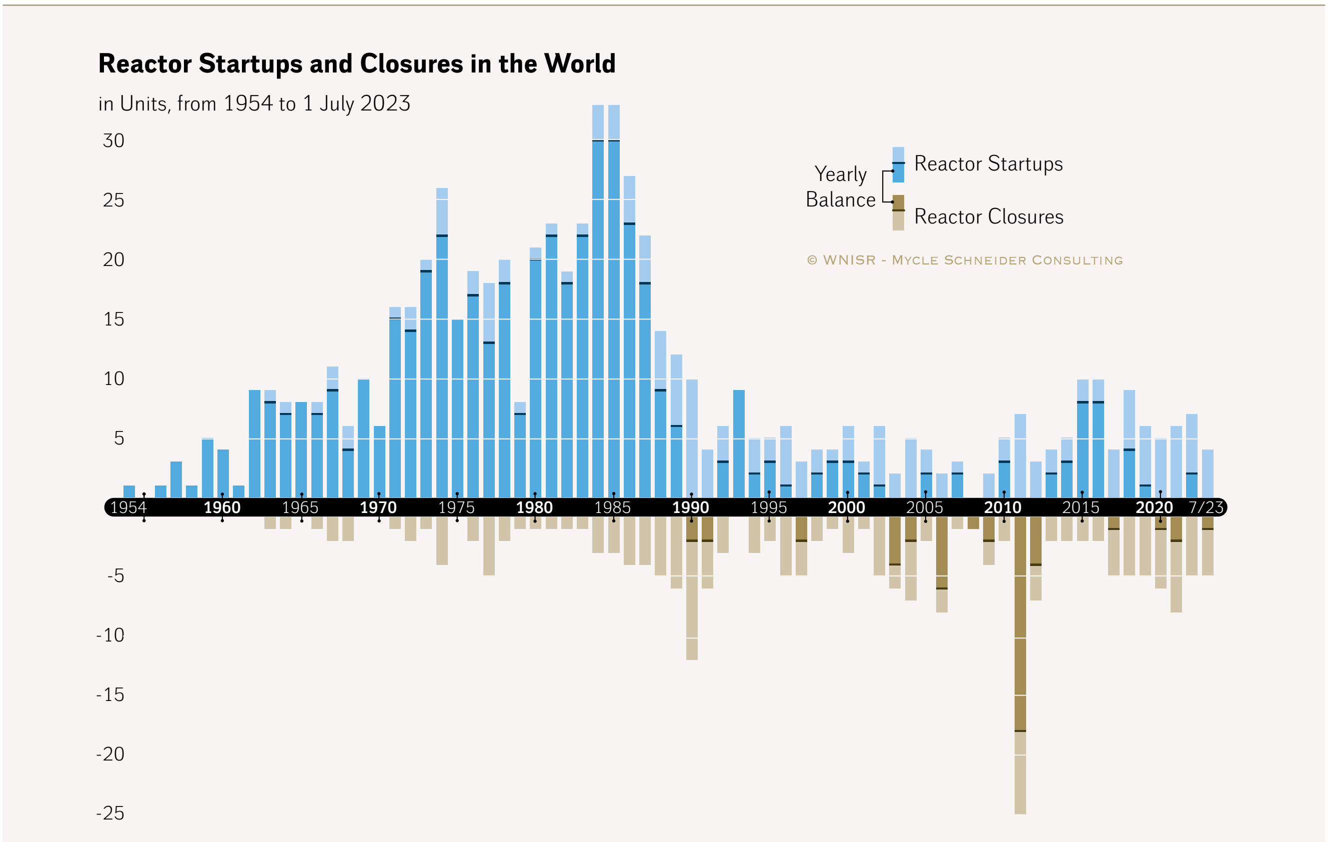
Since the first nuclear power reactor was connected to the Soviet power grid at Obninsk in 1954, there have been two major waves of startups. The first peaked in 1974, with 26 grid connections. The second reached a historic maximum in 1984 and 1985, just before the Chernobyl accident in 1986, reaching 33 grid connections in each year. By the end of the 1980s, the uninterrupted net increase of operating units had ceased, and in 1990 for the first time the number of reactor closures[22] outweighed the number of startups.

The 1993–2002 decade globally produced almost twice as many startups than closures (51/27), while in the decade 2003–2012, startups hardly exceeded half of the closures (33/63). Furthermore, it took the whole decade to connect as many units—33—as in a single year in the middle of the 1980s (see Figure 4).

In the past decade 2013–2022, 66 reactors were started-up—of which 39 (60 percent) in China—and 42 were closed.

22 - WNISR considers closure from the moment of grid disconnection—and not from the moment of the industrial, political, or economic decision—and as the units have not generated power for several years, in WNISR statistics, they are closed in the year of their last power generation.

Figure 4 · Nuclear Power Reactor Grid Connections and Closures in the World



Sources: WNISR, with IAEA-PRIS, 2023

Notes: WNISR considers reactors closed as of the date of their last electricity production, and not as of their closure announcement (which can be made years after the reactor ceased production).

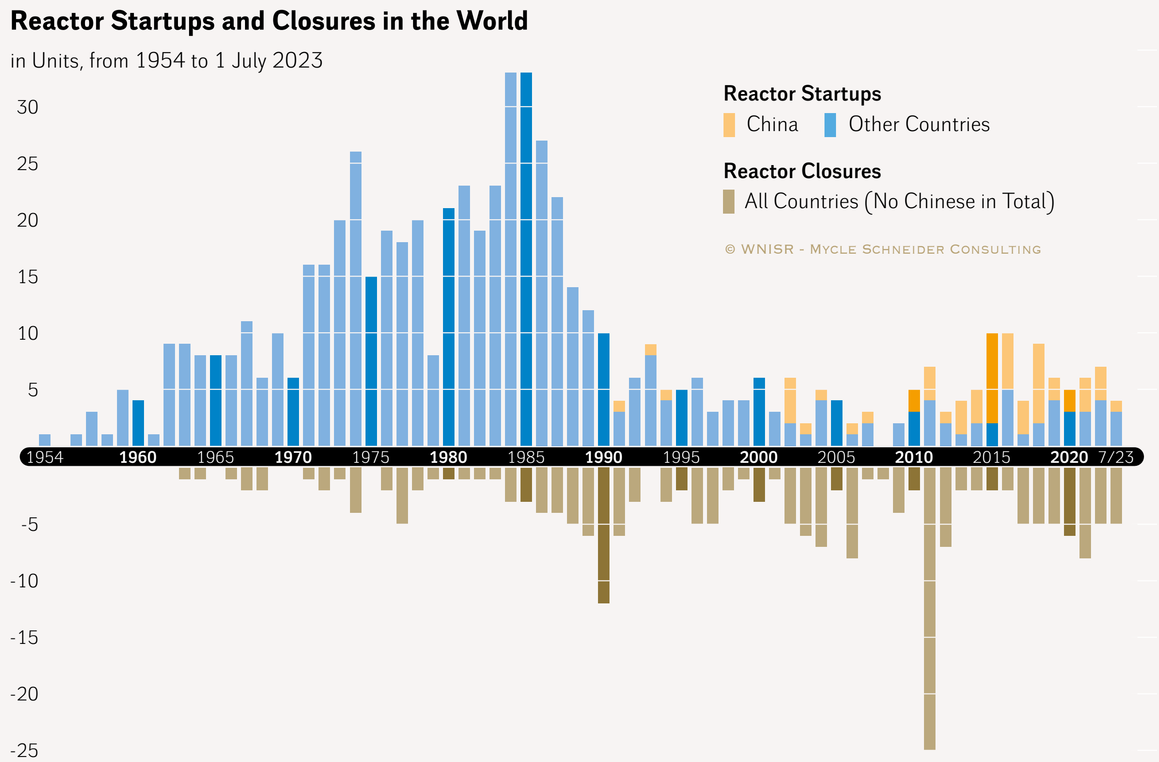
Over the two decades 2003–2022, there were 99 startups and 105 closures. Of these, 49 startups were in China which did not close any reactors. As a result, outside China, there has been a drastic net decline by 55 units over the same period (see Figure 5). As larger units were started up (totaling 90.7 GW) than closed (totaling 68.5 GW) the net nuclear capacity added worldwide over the 20-year period was 22.2 GW. However, since China alone added 46.8 GW, the net capacity outside China declined by almost 25 GW.

In 2021, six units were connected to the grid, of which three were in China, one each in India, Pakistan and the UAE, and eight were closed.

In 2022, seven reactors were connected to the grid, of which three in China and one each in Finland, Pakistan, South Korea, and the UAE, and five were closed, three in the U.K, and one each in Belgium and the U.S.

In the first half of 2023, four units were connected to the grid, one each in Belarus, China, Slovakia, and the U.S., and five were closed, three in Germany and one each in Belgium and Taiwan. (See Figure 5).

Figure 5 • Nuclear Power Reactor Grid Connections and Closures – The Continuing China Effect



Sources: WNISR, with IAEA-PRIS, 2023

As of 1 July 2023, a total of 407 nuclear reactors were operating in 32 countries, down four from the situation in mid-2022.[23] The current world fleet has a total electric net capacity of 365 GW, after it peaked at 368 GW at the end of 2022. As the annual statistics always reflect the status at year-end, the situation might change again by the end of 2023.

The number of operating reactors remains by eleven below the figure reached in 1989 and by 31 below the 2002 peak (see Figure 6).

For many years, the net installed capacity has continued to increase more than the net number of operating reactors. This is a result of the combined effects of larger units replacing smaller ones and "uprating". In 1989, the average size of an operational nuclear reactor was about 740 MW, in 2022 it was almost 900 MW. Technical alterations raised capacity at existing plants resulting in larger electricity output, a process known as uprating.[24] In the U.S. alone, the Nuclear Regulatory Commission (U.S. NRC) has approved 172 uprates since 1977. The cumulative approved uprates in the U.S. total 8 GW, the equivalent of eight large reactors. These include seven minor uprates (<2 percent of reactor capacity) approved since mid-2020, of which only one since mid-2021.[25]

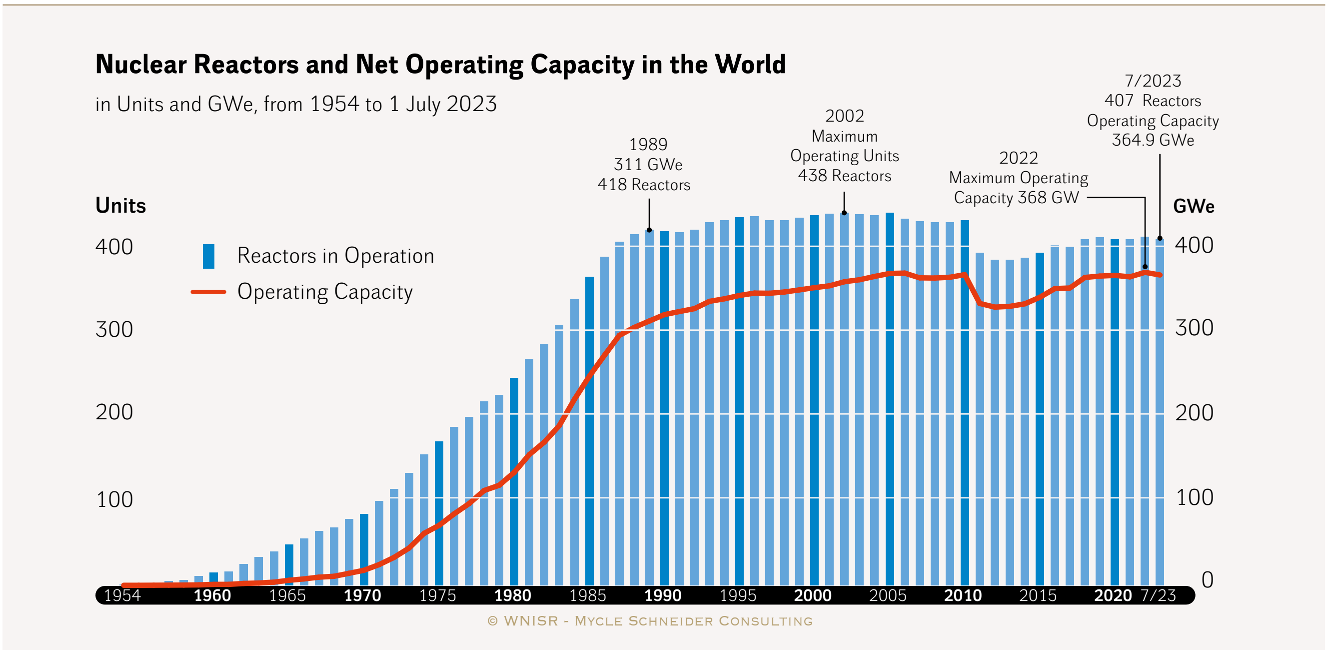
23 - +6 startups +1 restart –3 new LTO –8 closures.

24 - Increasing the capacity of nuclear reactors by equipment upgrades e.g. more powerful steam generators or turbines.

25 - U.S. NRC, "Approved Applications for Power Uprates", United States Nuclear Regulatory Commission, Updated 19 November 2021, see http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 4 August 2023.

A similar trend of uprates and major overhauls in view of lifetime extensions of existing reactors has been seen in Europe. The main incentive for lifetime extensions is economic but this argument is being increasingly challenged as refurbishment costs soar and alternatives become cheaper.

Figure 6 · World Nuclear Reactor Fleet, 1954–mid-2023



Sources: WNISR, with IAEA-PRIS, 2023

IAEA Unexpectedly and Quietly Revises Operating Reactor Data

Until September 2022, the IAEA's online Power Reactor Information System (PRIS) database counted 33 reactors as operational/operating in Japan, whereas 20 of these had not produced power since 2010–2012, and an additional three units had been shut down even since the Niigata Earthquake in 2007.

For almost a decade WNISR has been calling for an appropriate reflection in world nuclear statistics of the unique situation in Japan. The approach taken by the IAEA, the Japanese government, utilities, industry and many research bodies as well as other governments and organizations to continue classifying the entire stranded reactor fleet in the country as "in operation" or "operational" was clearly misleading.

Faced with this dilemma, the WNISR team in 2014 decided to create a new category with a simple definition, based on empirical fact, without room for speculation: "Long-Term Outage" or LTO. Its definition:

> A nuclear reactor is considered in Long-Term Outage or LTO if it has not generated any electricity in the previous calendar year and in the first half of the current calendar year. It is withdrawn from operational status retroactively from the day it has been disconnected from the grid.

When subsequently the decision is taken to close a reactor, the closure status starts with the day of the last electricity generation, and the WNISR statistics are retroactively modified accordingly.

Applying this definition to the world nuclear reactor fleet, as of 1 July 2023, leads to classifying 31 units in LTO, of which 23 in Japan, three in India (Madras-1, Tarapur-1 & -2), two in Canada (Bruce-6 and Darlington-3, restarted after refurbishment in the second half of 2023, after WNISR's statistical deadline), one in China (CEFR, which has been retrieved altogether from the IAEA-PRIS database in May 2023), one in France (Penly-1, restarted in July 2023 after statistical deadline), and Kori-2 in South Korea, whose license expired in April 2023, and is in the process of seeking a license renewal.

IAEA: Change is Coming – New Category "Suspended Operation"

Ten years ago, on 16 January 2013, the IAEA moved 47 reactors in Japan, most of them shut down in the aftermath of the Fukushima events in 2011, from the category "In Operation" into "Long-term Shutdown"[26] that existed in the IAEA statistical system until October 2022. Only two days later, the move was labelled a "clerical error" and the action was reversed at the request of the Japanese government.[27]

It is only in September 2022, that in the IAEA-PRIS database, twelve Japanese reactors[28] were gradually withdrawn from the list of "operating" or "operational" reactors, and their status changed to "Long-term Shutdown" (LTS). By mid-October 2022, the category title was changed to "Suspended Operation" on the PRIS website[29], and in November 2022, four more Japanese units[30] joined the new category as well as one Indian reactor (Rajastan-1) that has not generated any power since 2004 and is considered closed by WNISR.

As of the end of 2022, the PRIS database still counted 17 Japanese reactors as "in Operation". Whereas ten have effectively restarted since the beginning of the Fukushima disaster (also referred to as 3/11), the remaining seven have not produced any electricity since 2010–2012. Then, in April 2023, those seven units also joined the "Suspended Operation" category, followed in May 2023 by three additional Indian reactors, that have not produced power since 2018 (Madras-1) and 2020 (Tarapur-1 & -2).

The definition of the new category is as follows:

> A reactor is considered in the suspended operations status, if it has been shut down for an extended period (usually more than one year) and there is the intention to re-start the unit but:

26 - WNISR, "Historic Move: IAEA Shifts 47 Japanese Reactors Into "Long-Term Shutdown" Category", 16 January 2013, see https://www.worldnuclearreport.org/Historic-Move-IAEA-Shifts-47.html, accessed 14 November 2023.

27 - WNISR, "IAEA-Japan Reactor Status Incident: "Clerical Error" Explanation Not Credible", 20 January 2023, see https://www.worldnuclearreport.org/IAEA-Japan-Reactor-Status-Incident.html, accessed 14 November 2023.

28 - Kashiwazaki Kariwa 1–5, then Tomari 1–3, then Hamaoka 3–5, followed by Tsuruga-2.

29 - In fact, this category was already mentioned in the IAEA's "Nuclear Power in the World" booklet in May 2015, but never used in the Agency's online resources. It said: under "Long term shutdown (suspended operation)": "A unit is considered to be in long term shutdown if it has been shut down for an extended period (usually several years) initially without any firm recovery schedule, but with the intention to restart the unit eventually. Suspended operation is a new term for this status."

30 - Higashi Dori-1, Onagawa-3 and Shika-1 & -2.

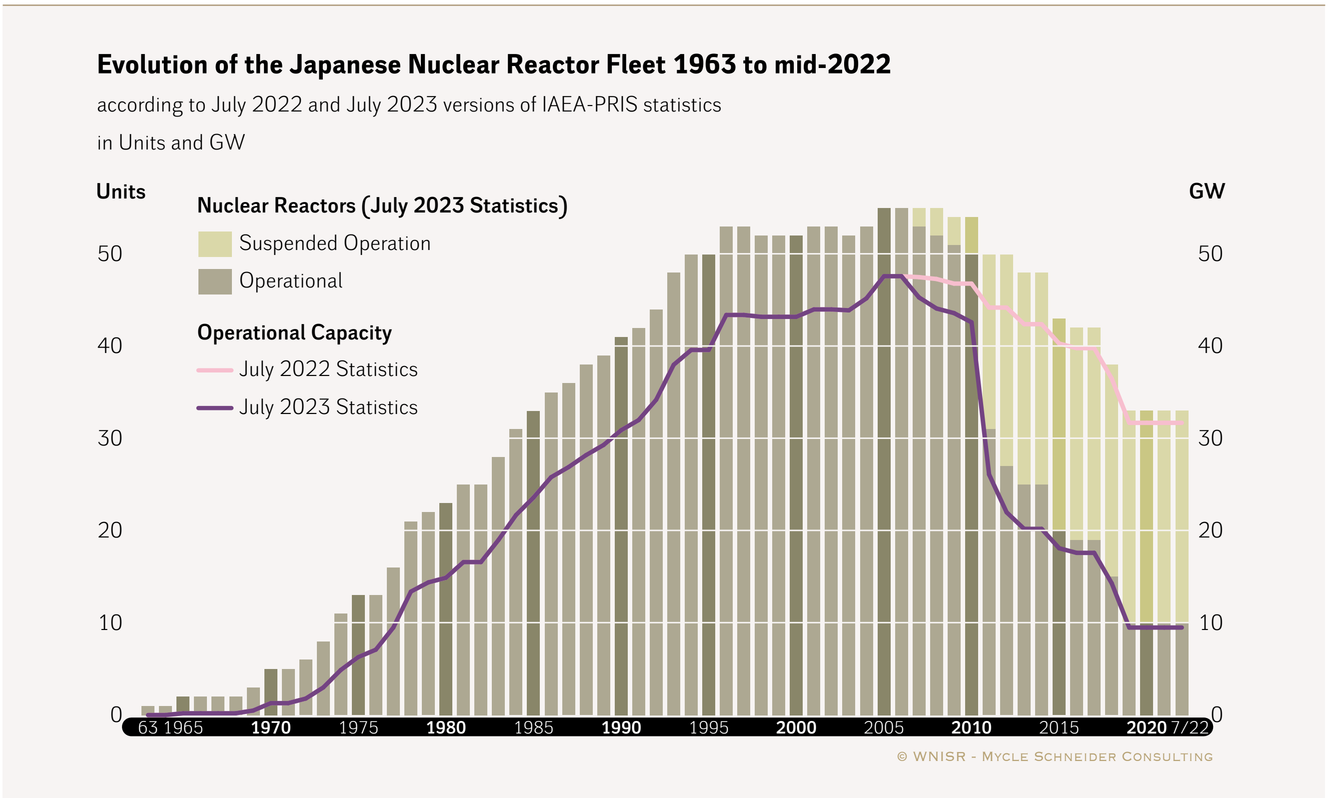
1. restart is not being aggressively pursued (there is no vigorous onsite activity to restart the unit) or

2. no firm restart date or recovery schedule has been established when unit was shutdown [shut down].

Suspended operations may be due to [~~due to~~] technical, economical, strategic or political reasons. This status does not apply to long-term maintenance outages, including unit refurbishment, if the outage schedule is consistently followed, or to long-term outages due to regulatory restrictions (licence suspension), if restart (licence recovery) term and conditions have been established. Such units are still considered "operational" (in a long-term outage). If an intention not to restart the shutdown unit has been officially announced by the owner, the unit is considered "permanently shutdown [shut down]".[31]

It is important to understand that the application of this new rule modifies retroactively *all of* the IAEA's statistics on operating reactors—in most cases as of day of last production—back to 2007. This dramatically modifies the IAEA's representation of the Japanese nuclear reactor fleet's evolution (see Figure 7). The changes obviously also impact the IAEA's representation of the long-term evolution of the entire global nuclear power-reactor fleet (see Figure 8).

Figure 7 • Evolution of the Japanese Nuclear Reactor Fleet, 1963 to mid-2022



Sources: IAEA-PRIS, July 2022 and July 2023

Note: All reactors listed in the "Suspended Operation" category as of July 2023, were considered Operational in July 2022 statistics.

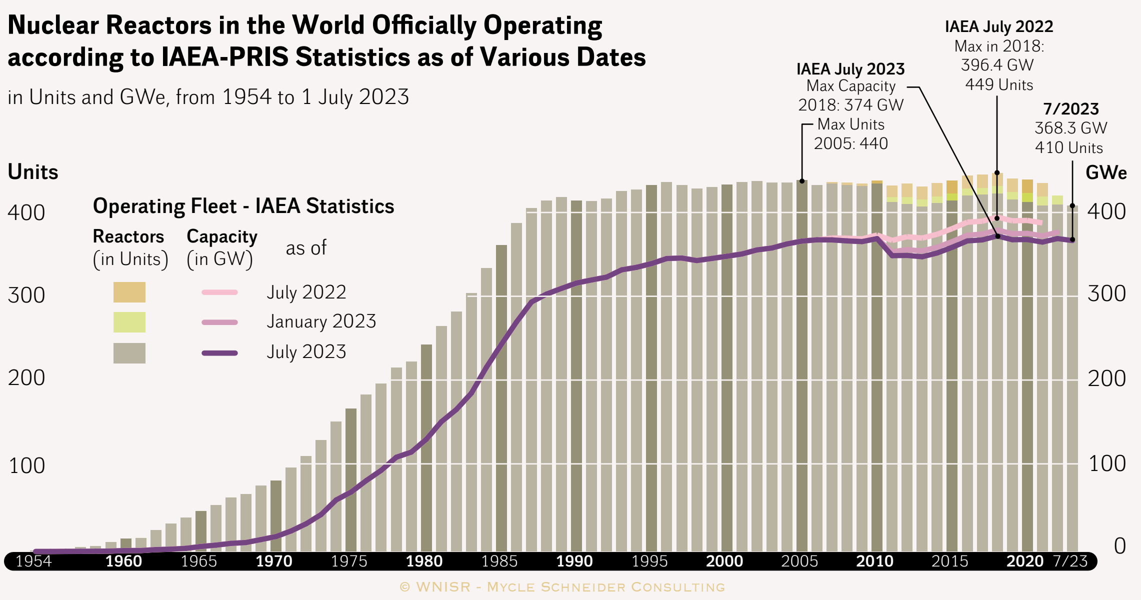
31 - IAEA-PRIS, "Glossary of Terms in PRIS Reports", Power Reactor Information System, International Atomic Energy Agency, 2023, see https://pris.iaea.org/PRIS/Glossary.aspx, accessed 14 November 2023.

While now reflected on the PRIS Homepage[32] and the PRIS Japan Country Details page[33], *all of those changes* happened without any public announcement or online explanation. The IAEA has argued in the past that they only serve as the "database manager", the IAEA being only in a position to provide suggestions, with all changes ultimately being decided by Member States officials and implemented in the PRIS database by the respective Government appointed data providers, the "correspondents".

Apparently, there have been lengthy discussions for several years between the IAEA and the Japanese correspondents on how to address the obvious mislabeling of stranded reactors as "in operation". In view of public perception, the Japanese government was eager to avoid the term "shutdown" as many of the reactors were officially planned to be restarted (see Japan Focus).

The differences with WNISR statistics are greatly reduced, and the remaining ones mostly relate to official closure dates, as WNISR statistics consider the end of electricity production as reference for dating closures, and not the "announcement" or "political decision" to permanently withdraw a reactor from the grid (see also IAEA Unexpectedly and Quietly Revises Operating Reactor Data above).

Figure 8 • World Nuclear Reactor Fleet – IAEA-PRIS Statistics Evolving Over Time



Sources: IAEA-PRIS statistics as of July 2022, January 2023 and July 2023

Notes: The IAEA data used for this graph includes at least three reactors that have been later withdrawn from the PRIS statistics for operating reactors (Niederaichbach, VAK-Kahl and HDR Großwelzheim, in Germany, now only appearing as "Decommissioning Completed"). On the other hand, the Swiss research reactor in Lucens is not included.

The Chinese CEFR was retrieved from the IAEA-PRIS statistics in May 2023 and is therefore only included in July 2022 and January 2023 datasets. Reactors classified as in "Suspended Operation" by the IAEA are not represented here.

32 - IAEA-PRIS, "The Database on Nuclear Power Reactors", 2023, see https://pris.iaea.org/pris/, accessed 14 November 2023.

33 - IAEA-PRIS, "Country Statistics—Japan", 2023, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, accessed 14 November 2023.

As of July 2022, according to the IAEA-PRIS statistics, the evolution of the world nuclear fleet showed a peak of officially operating reactors in 2018, both in terms of number and capacity, with 449 reactors and a maximum capacity of 396.4 GW, declining since. The corresponding data for the end of 2021 showed 437 reactors in operation with a capacity of 389.5 GW.[34]

The July 2023 data obviously offers a different picture: If the *operating capacity* still peaked in 2018 in those revised statistics, it only reached 374.1 GW, 22.3 GW less than the 396.4 GW previously indicated, whereas the number of *operating reactors* never exceeded the number of 440, reached already in 2005.

IAEA vs. WNISR Assessment

WNISR's assessment of "operating" reactors has shown significant differences with IAEA statistics since the beginning of the Fukushima disaster in 2011. However, after major changes in the PRIS statistics (see IAEA Unexpectedly and Quietly Revises Operating Reactor Data and IAEA: Change is Coming – New Category "Suspended Operation" above), those differences were reduced to minor disparities during the period September 2022 to May 2023, compared to WNISR2022.

The following section provides a detailed explanation and justification of the differences.

Figure 9 presents the evolution of the number and capacity of the world reactor fleet "in operation" as reported by the IAEA vs. WNISR.

As of July 2023, the evolution of the world nuclear fleet in the PRIS statistics shows a peak of 440 reactors operating in 2005, while the operating capacity reached a maximum of 374 GW in 2018; as of end 2022, the operating capacity was 371 GW. In the WNISR statistics, which consider reactors closed from the day they stop producing electricity, and systematically apply the LTO status to reactors not operating for a certain period, a maximum number of 438 reactors was reached as soon as 2002, and again in 2005. The operating capacity slightly increased in 2022 beyond the previous peak of 2006, to reach a maximum of 368 GW.

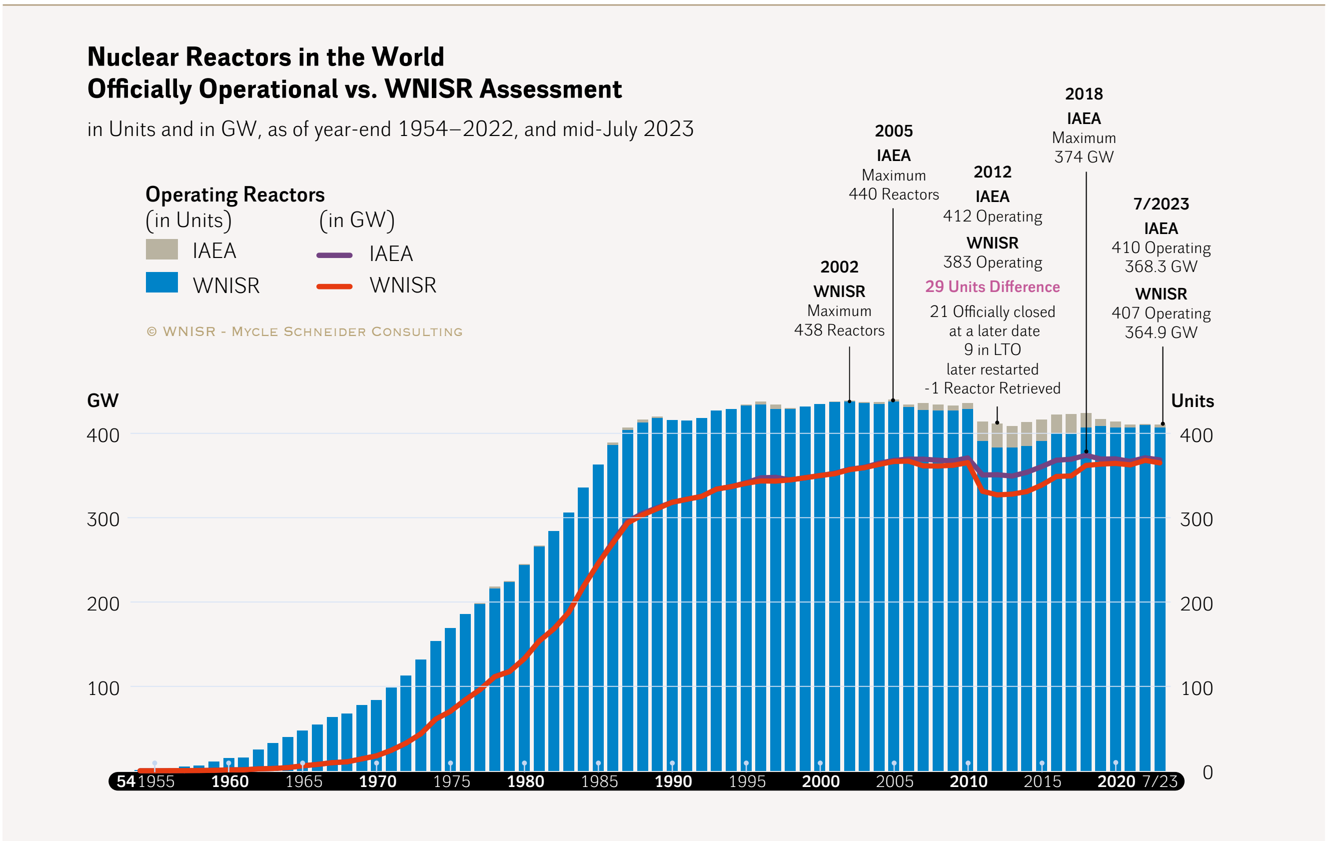
Although not the only case, the Japanese fleet still provides the main and more visible differences, especially over the past decade. This applies both to reactors that did not produce electricity for many years before they returned to service (designated as "LTO later restarted" or "Restarted from LTO"), or which were declared permanently closed years after they stopped producing electricity ("Closed at a later date").

Applying this definition to the world nuclear reactor fleet, as of 1 July 2023, leads to classifying four units considered "in operation" by the IAEA as LTO:

34 - Marta M. Gospodarczyk, "Amid Global Crises, Nuclear Power Provides Energy Security with Increased Electricity Generation in 2021", Department of Nuclear Energy, International Atomic Energy Agency, 14 July 2022, see https://www.iaea.org/newscenter/news/amid-global-crises-nuclear-power-provides-energy-security-with-increased-electricity-generation-in-2021, accessed 14 November 2023.

- Bruce-6 and Darlington-3, under refurbishment since January and July 2020 respectively. They came back online in the second half of 2023[35] (see section on Canada in Annex 1).
- Penly-1, shut down on 2 October 2021 for its third decennial inspection, reconnected to the grid on 13 July 2023 (see France Focus).[36]
- Kori-2 in South Korea, shut down in April 2023, after 40 years of operation, is expected to be restarted at an unknown date, and is therefore considered in LTO.

Figure 9 · World Nuclear Reactor Fleet – IAEA vs. WNISR, 1954–July 2023



Sources: IAEA-PRIS and WNISR, 2023

Notes: The IAEA data used for this graph includes at least three reactors that have been later withdrawn from the PRIS statistics for operating reactors (Niederaichbach, VAK-Kahl and HDR Großwelzheim, in Germany, now only appearing as "Decommissioning Completed"). On the other hand, the Swiss research reactor in Lucens is not included. Reactors classified as in "Suspended Operation" by the IAEA are not represented here.
Although the total number of reactors in operation according to WNISR statistics has always remained, albeit slightly, inferior to IAEA-PRIS data, it contains Chinese reactors not accounted for in PRIS (see below).

35 - Darlington-3 was reconnected to the grid in July 2023; see OPG, "OPG celebrates the early completion of Darlington Unit 3", Press Release, Ontario Power Generation, 18 July 2023, see https://www.opg.com/media_releases/opg-celebrates-the-early-completion-of-darlington-unit-3/, accessed 19 July 2023; and Bruce-6 in September 2023; see Bruce Power, "Bruce Power's renewed Unit 6 declared commercially operational on 39th anniversary of first in-service date", 14 September 2023, see https://www.brucepower.com/2023/09/14/bruce-powers-renewed-unit-6-declared-commercially-operational-on-39th-anniversary-of-first-in-service-date/, accessed 8 November 2023.

36 - EDF, "Les deux unités de production de la centrale nucléaire de Penly connectées au réseau électrique national", Press Release (in French), 14 July 2023, see https://www.edf.fr/la-centrale-nucleaire-de-penly/les-actualites-de-la-centrale-nucleaire-de-penly/les-deux-unites-de-production-de-la-centrale-nucleaire-de-penly-connectees-au-reseau-electrique-national, accessed 14 July 2023.

But on the other hand, WNISR statistics do include additional reactors in China:

- Shidao-Bay-1: The IAEA considers the two 100-MW modules as one reactor as they drive a single 200-MW turbine. WNISR considers that each module is a separate reactor.
- CEFR: The IAEA has simply deleted the file for the reactor without any indication of reasons. Chinese sources have argued it should have never been in the IAEA's PRIS database in the first place as it is to be considered an experimental reactor. However, as this is a nuclear power reactor, it is considered as such by WNISR. Its current operational status is uncertain. In the absence of operational data, WNISR considers it in LTO as of May 2023 (but still operating as of December 2022).[37]

The biggest difference between IAEA-PRIS and WNISR is found as of the end of 2012, with 29 units less operating according to WNISR criteria: the IAEA-PRIS counts 30 reactors (detailed in Table 1) that are not considered operating according to WNISR, but on the other hand has retrieved the Chinese CEFR it previously considered operational at this date.

Table 1 · WNISR Rationale for the Classification of 30 Reactors as Non-Operational as of end 2012

Countries	Officially Closed at a Later Date 21 Reactors		Restarted from LTO 9 Reactors
	Reactors that last produced electricity in (or prior to) 2012, officially closed after 2012 (either considered closed by WNISR as early as 2012, or after a certain period in LTO). Most of those reactors were considered "in operation" for many years before their official closure date.		
	Reactors considered closed in 2012	Reactors in LTO prior to closure	Reactors in LTO as of December 2012 Restarted prior to 1 July 2023
Japan	6 Reactors Fukushima Daiichi 5–6 Fukushima Daini 1–4 Officially Closed in 2013 and 2019	11 Reactors Last production in 2010–2012 Officially closed 2015–2019	8 Reactors Restarted 2015–2021
South Korea			1 Reactor Wolsong-1, Restarted in 2015
Spain	1 Reactor Santa Maria de Garoña Last production in 2012 Officially Closed in 2017*		
U.S.	3 Reactors San Onofre-2 & -3 Last production in 2012 Officially closed in 2013 Crystal River-3 Last production in 2009 Officially closed in 2013		

Sources: IAEA-PRIS and WNISR, 2023

Note: *Garoña was subsequently considered in "Suspended Operation" during 2013–2016 by the IAEA until its official closure.

The differences between the IAEA and WNISR are not limited to the effects of the Fukushima disaster. Even prior to 3/11, WNISR and IAEA-PRIS data had differences, reaching up to 10 units at the end of some years. These differences were mainly due to the definition of the closure

37 - CEFR was considered in LTO in WNISR statistics from 2017 to 2020, until it was reconnected to the grid in February 2021; see *WNN*, "Chinese fast reactor begins high-power operation", 19 February 2021, *World Nuclear News*, see https://www.world-nuclear-news.org/Articles/Chinese-fast-reactor-begins-high-power-operation, accessed 8 November 2023.

date that the IAEA sometimes sets at last production and sometimes as closure-decision date while WNISR systematically applies the day of last electricity generation (when available).

OVERVIEW OF CURRENT NEW-BUILD

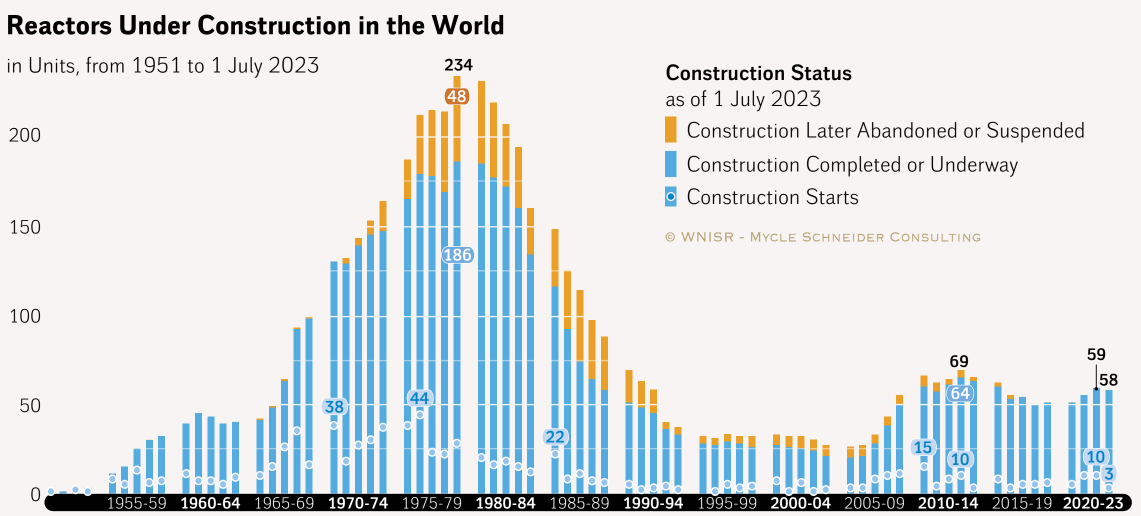
As of 1 July 2023, 58 reactors were considered as under construction, five more than the WNISR reported a year ago, but 11 fewer than in 2013 (of the 69 reactors under construction at the end of 2013, four units have subsequently been abandoned). The number includes 23 units (40 percent) being built in China.

Four in five reactors are built in Asia or Eastern Europe (see Building vs. Vendor Countries). In total, 16 countries are building nuclear plants, with a (provisional?) construction restart in Brazil, new construction in Egypt, and Belarus having started up its second and only reactor under construction, that is one more country than in WNISR2022.

However, only four countries—China, India, Russia, and South Korea—have construction ongoing at more than one site, and eight countries only have a single reactor under construction (see Table 2 and Annex 3 for details). Since mid-2022, construction of ten new units was launched worldwide, including four in China and three in Egypt.

The 58 reactors listed as under construction by mid-2023 compared with 234 units—totaling more than 200 GW—in 1979. However, many (48) of those projects listed then were never finished (see Figure 10). The year 2005, with 26 units listed as under construction, was the lowest since the early nuclear age in the 1950s.

Figure 10 • Nuclear Reactors "Under Construction" in the World

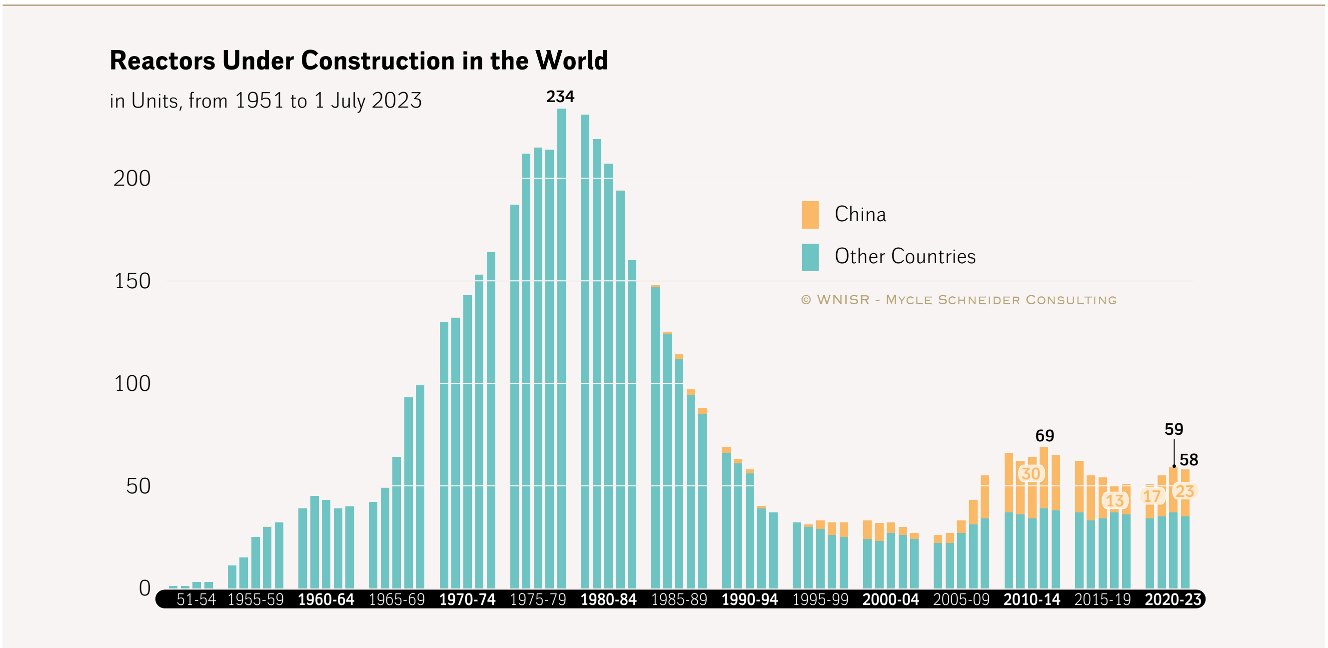


Sources: WNISR, with IAEA-PRIS, 2023

Notes: This figure includes construction of two CAP1400 reactors at Rongcheng/Shidaowan, although their construction has not been officially announced (see China Focus). At Shidao Bay, the HTR plant, where construction started in 2012, has two reactor modules on the site and is therefore counted as two units as of WNISR2020. Grid connection of the first unit of the twin reactors officially took place on 20 December 2021. No date was provided for startup of the second reactor, which is considered as operating in WNISR2023 as of end-2022 (see China Focus for details).

Compared to the year before, the total capacity of the 58 units under construction in the world in mid-2023 increased by 5.3 GW to 58.6 GW, with an average unit size of 1,010 MW.

Figure 11 • Nuclear Reactors "Under Construction" – China and the World (as of 1 July 2023)



Sources: WNISR, with IAEA-PRIS, 2023

BUILDING VS. VENDOR COUNTRIES

As of mid-2023, China has by far the most reactors (23 units) under construction in the world. However, it is currently not building anywhere outside the country and has only exported to Pakistan. Russia is in fact largely dominating the international market as a technology supplier with 24 units under construction in the world, as of mid-2023, of which only five are domestic and 19 in seven different countries, including four each in China, India, and Turkey, three in Egypt and two in Bangladesh. It is uncertain to what extent these projects will be impacted by the various layers of sanctions imposed on Russia following the invasion of Ukraine.

Besides Russia's Rosatom, there are only French and South Korean companies building abroad (see Table 2 and Figure 12).

Table 2 · Nuclear Reactors "Under Construction" (as of 1 July 2023)[38]

Country	Units (Domestic Design)	Other Vendor	Capacity (MW net)	Construction Start	Grid Connection	Units Behind Schedule
China	23 (19)	Russia: 4	24 408	2016 – 2023	2023 – 2028	1
India	8 (4)	Russia: 4	6 028	2004 – 2021	2024 – 2027	6[(a)]
Russia	5 (5)	–	2 810	2018 – 2022	2025 – 2027	2
Turkey	4 (0)	Russia: 4	4 456	2018 – 2022	2024 – 2027	1
Egypt	3 (0)	Russia: 3	3 300	2022 – 2023	2028 – 2030	-
South Korea	3 (3)	–	4 020	2013 – 2018	2024 – 2025	3
Bangladesh	2 (0)	Russia: 2	2 160	2017 – 2018	2024	1
U.K.	2 (0)	France: 2	3 260	2018 – 2019	2027 – 2028	2
Argentina	1 (1)	–	25	2014	2027	1
Brazil	1 (0)[(b)]		1 340	2010	2028?	1
France	1 (1)	–	1 630	2007	2024	1
Iran	1 (0)	Russia: 1	974	1976	2024	1
Japan	1 (1)	–	1 325	2007	2025?	1
Slovakia	1 (0)	Russia: 1[(c)]	440	1985	2024	1
UAE	1 (0)	South Korea: 1	1 310	2015	2023	1
U.S.	1 (1)	–	1 117	2013	2023	1
Total	58		58 603	1976 – 2023	2023 – 2030	24
Total per Vendor Country: Russia: 24 - China: 19 - India: 4 – South Korea: 4 - France: 3 - U.S.: 1 - Argentina: 1 - Japan: 1						

Sources: Various, compiled by WNISR, 2023

Notes:

(a) - Of the eight reactor projects under construction, all are delayed or likely to be delayed, with all Kudankulam reactors under construction "likely to be impacted" by the war in Ukraine. Six is the number of reactors "formally" delayed. See section on India in Annex 1, and Annex 3.

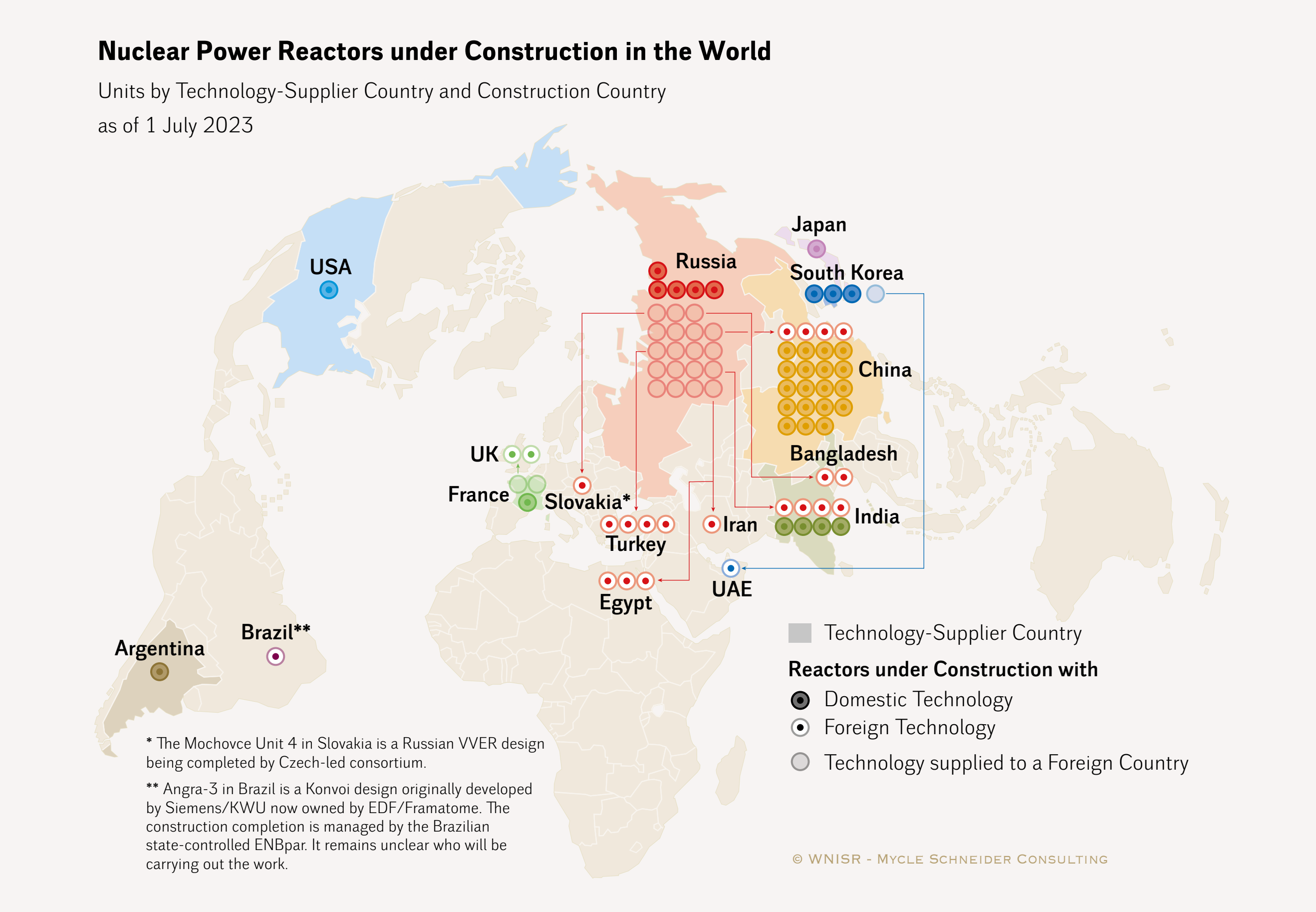
(b) - Angra-3 in Brazil is a Konvoi design originally developed by Siemens/KWU now owned by EDF/Framatome. The construction completion is managed by the Brazilian state-controlled ENBpar. It remains unclear who will be carrying out the work.

(c) - Mochovce -4 is a Russian VVER design being completed by a Czech-led consortium.

This table does not contain suspended or abandoned constructions. It does include construction of two CAP1400 reactors at Rongcheng/Shidaowan, although that has not been officially announced (see China Focus) as well as two floating reactors of Russian design to be deployed in Russia—thus counted under Country-Russia, but with the barges built in China.

38 - For further details, see Annex 3.

Figure 12 · Nuclear Reactors "Under Construction" by Technology-Supplier Country



Sources: WNISR, with IAEA-PRIS, 2023

CONSTRUCTION TIMES

Construction Times of Reactors *Currently Under Construction*

A closer look at projects listed as "under construction" as of 1 July 2023 illustrates the level of uncertainty and problems associated with many of these projects, especially given that most builders still assume a five-year construction period:

- For the 58 reactors being built, an average of 6 years has passed since construction start—slightly lower than the mid-2022 average of 6.8 years—and many remain far from completion.
- *All* reactors under construction in at least 10 of the 16 countries have experienced often year-long delays. Almost half (28) of the building projects are delayed or likely to be delayed. Most of the units which are nominally being built on-time (yet) were begun within the past three years or have not yet reached projected startup dates, making it difficult to assess whether they are on schedule. Significant uncertainty remains over construction in China because of lack of access to information. Five of six units that started building prior to 2020 and are not yet documented as delayed are located in China and one in Bangladesh.

The latter, Rooppur-2 is likely to be late, but it is not yet documented. It remains also unclear what will happen with Russian designed and/or implemented projects in six other countries, as sanctions have or will likely have an impact on supply chains.

- Of the 24 reactors clearly documented as behind schedule, at least nine have reported *increased* delays and one has reported a delay for the first time over the past year.
- WNISR2021 noted a total of 12 reactors scheduled for startup in 2022. At the beginning of 2022, 16 were still planned to be connected to the grid (including four pushed back from 2021 to 2022) but only seven of these made it, while the other 9 were delayed at least into 2023.
- Initial construction start of the Mochovce-4 reactor in Slovakia dates back 38 years and its grid connection has been further delayed, currently to 2024. Bushehr-2 in Iran originally started construction in 1976, over 47 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2024.
- Seven additional reactors have been listed as "under construction" for a decade or more: Angra-3 in Brazil, the Prototype Fast Breeder Reactor (PFBR), Kakrapar-4 and Rajasthan-7 & -8 in India, Shimane-3 in Japan, and Flamanville-3 (FL3) in France. The French and Indian projects have been further delayed this year, and the Japanese reactor does not even have a provisional startup date. Angra-3 construction, which initially started in 2010, was halted in 2015, apparently resumed in 2022, with an expected startup date of 2028. However, construction activities have been interrupted repeatedly.

The actual lead time for nuclear plant projects includes not only the construction itself but also lengthy licensing procedures in most countries, complex financing negotiations, site preparation, and other infrastructure development.

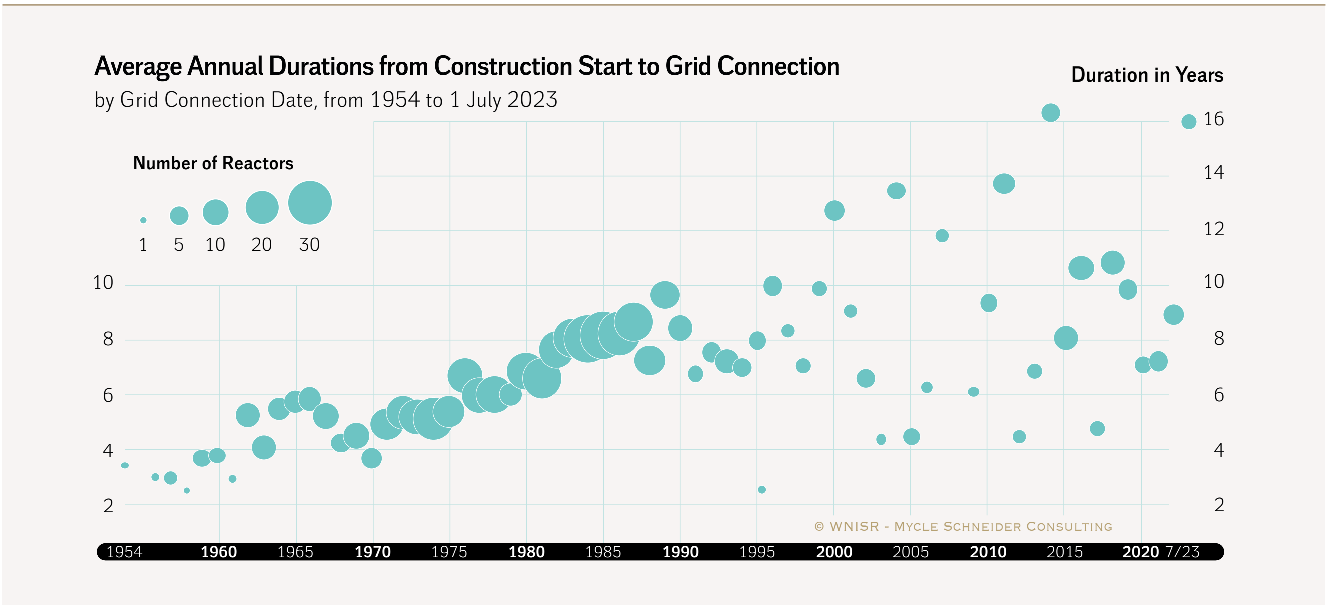
Construction Times of *Past and Currently Operating* Reactors

Since the beginning of the nuclear power age, there has been a clear global trend towards increasing construction times. National building programs were faster in the early years of nuclear power, when units were smaller, and safety and environmental regulations were less stringent. As Figure 13 illustrates, average times between construction start and grid connection of reactors completed in the 1970s and 1980s were quite homogenous, while in the past two decades they have varied widely.

The eight units completed in 2020–2022 in China took on average 6.4 years to build, while it took 10.5 years to finalize one project in Russia (compared to an average 15 years for the period 2018–2020).

As Figure 14 shows for the period 2020–2022, the longest construction time was for the Olkiluoto-3 (OL3) reactor (16.6 years), a Franco-German project, the first European Pressurized Water Reactor (EPR) to start up in Europe, twelve years later than planned. The longest construction times in Russia and China were seen for the EPR at Taishan-2 (9.2 years), the first reactor of the two HTR module at Shidao Bay-1 (9.1 years) and Leningrad 2-2 (10.5 years).

Figure 13 • Average Annual Construction Times in the World



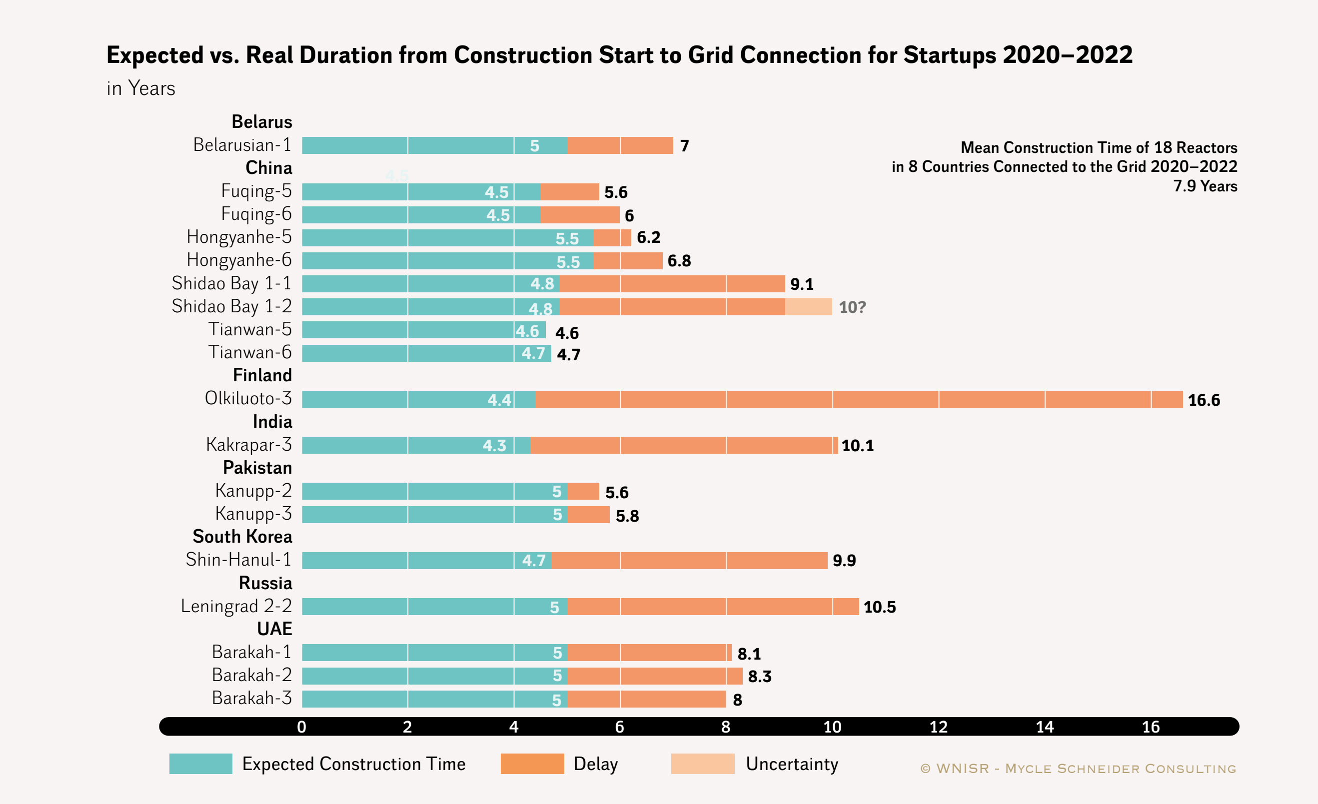
Sources: WNISR, with IAEA-PRIS, 2023

The mean time from construction start to grid connection for the seven reactors started up in 2022 was nine years, 1.7 years more on average than construction times of units started up in 2021 (7.3 years). In the case of the four units connected in the first half of 2023 to power grids in Belarus, China, Slovakia, and the U.S., the average time from first basemat concreting to first power generation was 16 years. This includes Mochovce-3 in Slovakia, with construction starting first in 1985.

Over the three years 2020–2022, only two of 18 units connected to the grid in seven countries started up on-time. Those are Tianwan-4 and -5 in China, Russian-designed but mainly Chinese-built VVER-1000s (model V-428M), that the designers claim to belong to Generation III (Gen III) classification, but few details are known.

The longer-term perspective confirms that short construction times remain the exceptions. Ten countries completed 66 reactors over the decade 2013–2022—of which 39 in China alone—with an average construction time of 9.4 years (see Table 3), slightly higher than the 9.2 years of mean construction time in the decade 2012–2021.

Figure 14 · Delays for Units Started Up 2020–2022



Sources: Various, compiled by WNISR, 2023

Note: Expected construction time is based on grid connection data provided at construction start when available; alternatively, best estimates are used, based on commercial operation, completion, or commissioning information.

At Shidao Bay, the HTR plant, where construction started in 2012, has two reactor modules on the site and is therefore counted as two units as of WNISR2020. Grid connection of the first unit of the twin reactors officially took place on 20 December 2021. No date was provided for startup of the second reactor, which is considered as operating in WNISR2023 as of end-2022, and total construction time set at 10 years.

Table 3 · Duration from Construction Start to Grid Connection, 2013–2022

Construction Times of 66 Units Started-up 2013–2022				
Country	Units	Construction Time (in Years)		
		Mean Time	Minimum	Maximum
China	39	6.2	4.1	10.0
Russia	9	17.9	8.1	35.1
South Korea	4	8.3	6.4	9.9
Pakistan	4	5.6	5.5	5.8
India	3	12.0	10.1	14.2
UAE	3	8.1	8.0	8.3
Argentina	1	33.0	33	
Belarus	1	7.0	7.0	
Finland	1	16.6	16.6	
U.S.	1	42.8	42.8	
World	**66**	**9.4**	**4.1**	**42.8**

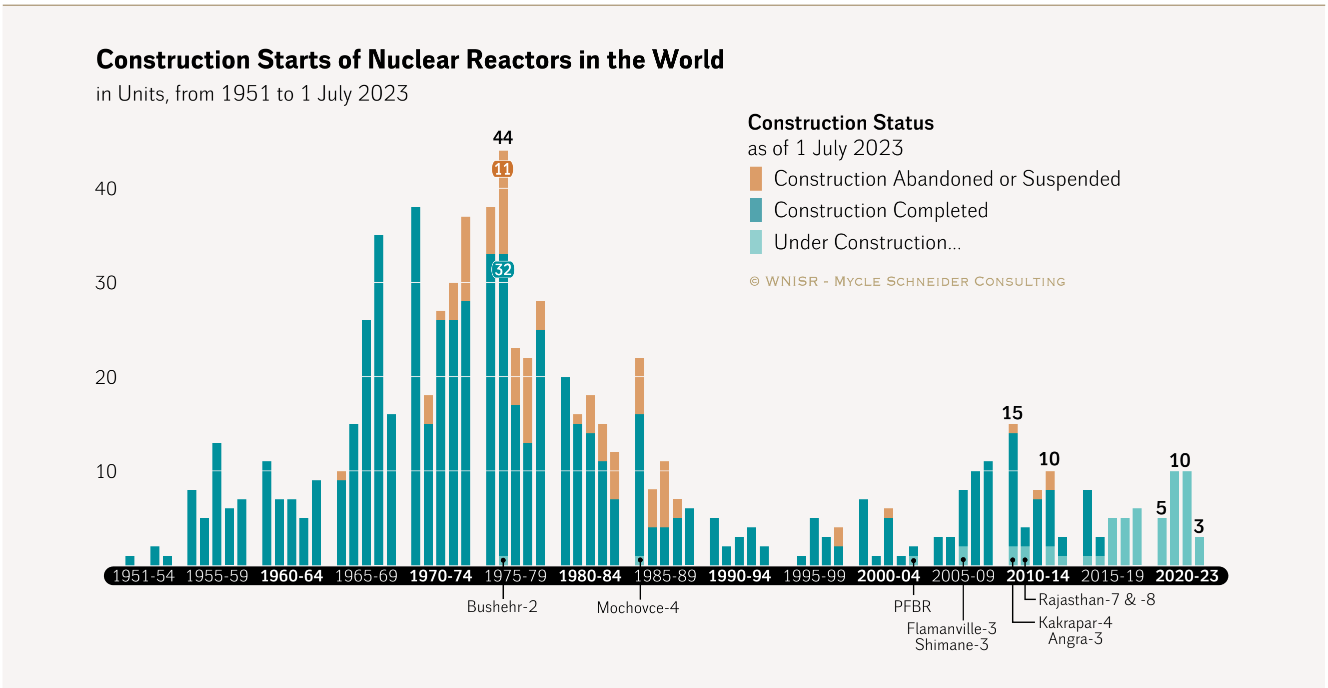
Sources: Various, compiled by WNISR, 2023

CONSTRUCTION STARTS AND CANCELLATIONS

The number of annual construction starts[39] in the world peaked in 1976 at 44, of which 11 projects were later abandoned. In 2010, there were 15 construction starts—including 10 in China—the highest level since 1985 (see Figure 15 and Figure 16). That number dropped to five in 2020 (including four in China, while building started on ten units in 2021 (including 6 in China), as well as in 2022 (including five in China). The other five units are implemented by the Russian nuclear industry in Egypt (2), in Turkey (1) and domestically (2), while two of the construction starts in China were also carried out by the Russian industry. In other words, of the global total of ten, seven reactors were by Russian builders and three by the Chinese industry.

Three reactors got underway in the world in the first half of 2023, two of them in China, and one of Russian design in Egypt. Chinese and Russian government-owned or -controlled companies launched all 28 reactor constructions in the world over the 42-month period from the beginning of 2020 to mid-2023.

Figure 15 · Construction Starts in the World



Sources: WNISR, with IAEA-PRIS, 2023

Notes: Construction of Bushehr-2 in Iran started in 1976, was considered abandoned in earlier versions of this figure. As construction was restarted in 2019, it now appears as "Under Construction". Albeit of uncertain future, construction of Angra-3 in Brazil is considered restarted.

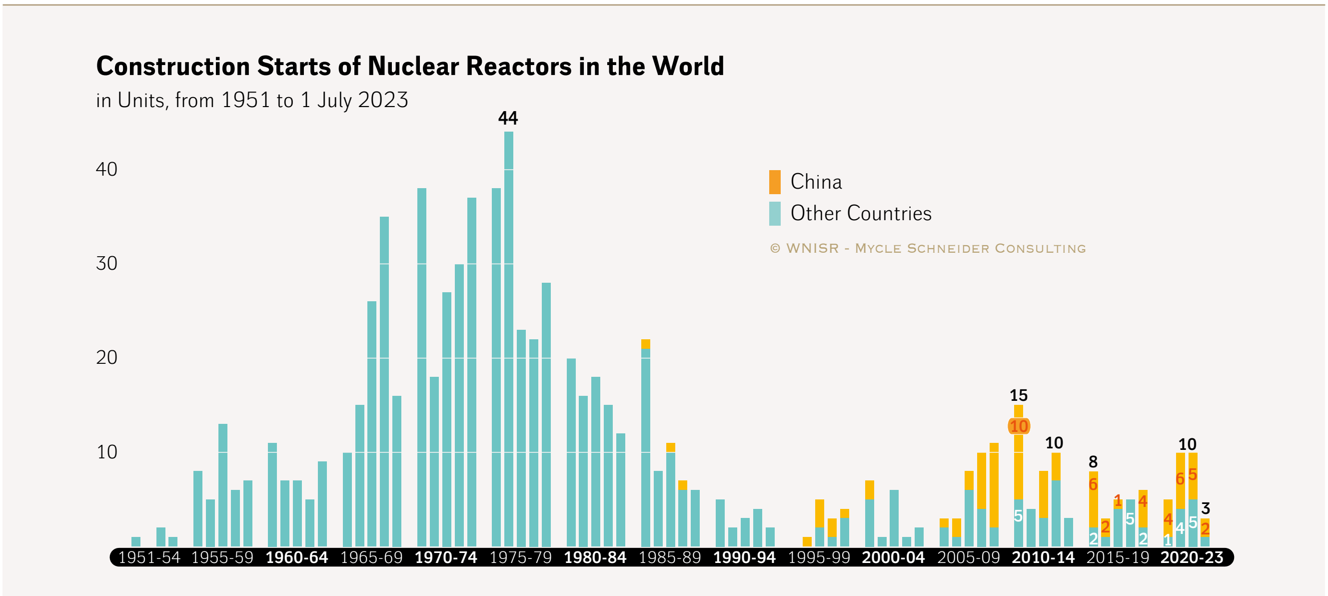
Over the decade 2013–2022, construction began on 65 reactors in the world, of which almost half (31) in China. Two of these building sites have been abandoned over the

39 - Generally, a reactor is considered under construction with the beginning of the concreting of the base slab of the reactor building. Site preparation work, excavation and other infrastructure developments are not included.

period (V.C. Summer-2 and -3 in the U.S.). As of mid-2023, 17 of the remaining 63 units had started up, while 46 remain under construction.

Seriously affected by the Fukushima events, China did not start any construction in 2011 and 2014 and began work only on seven units in total in 2012 and 2013. While Chinese utilities started building six more units in 2015, the number shrank to two in 2016, only a demonstration fast reactor in 2017, none in 2018, but four each in 2019 and 2020, six in 2021, five in 2022 and two in the first half of 2023 (see Figure 16). While this increase represents a sign of the restart of commercial reactor building in China, the level continues to remain far below expectations. The five-year plan 2016–2020 had fixed a target of 58 GW operating and 30 GW under construction by 2020. As of the end of 2020, China had 49 units with 47.5 GW operating, one reactor in LTO (CEFR), and 17 units (16 GW) under construction, much lower than the original target. At the end of 2022, 56 reactors with a total capacity of 52.2 GW were operating and 22 units (23.1 GW) were under construction (for details, see China Focus).

Figure 16 • Construction Starts in the World/China



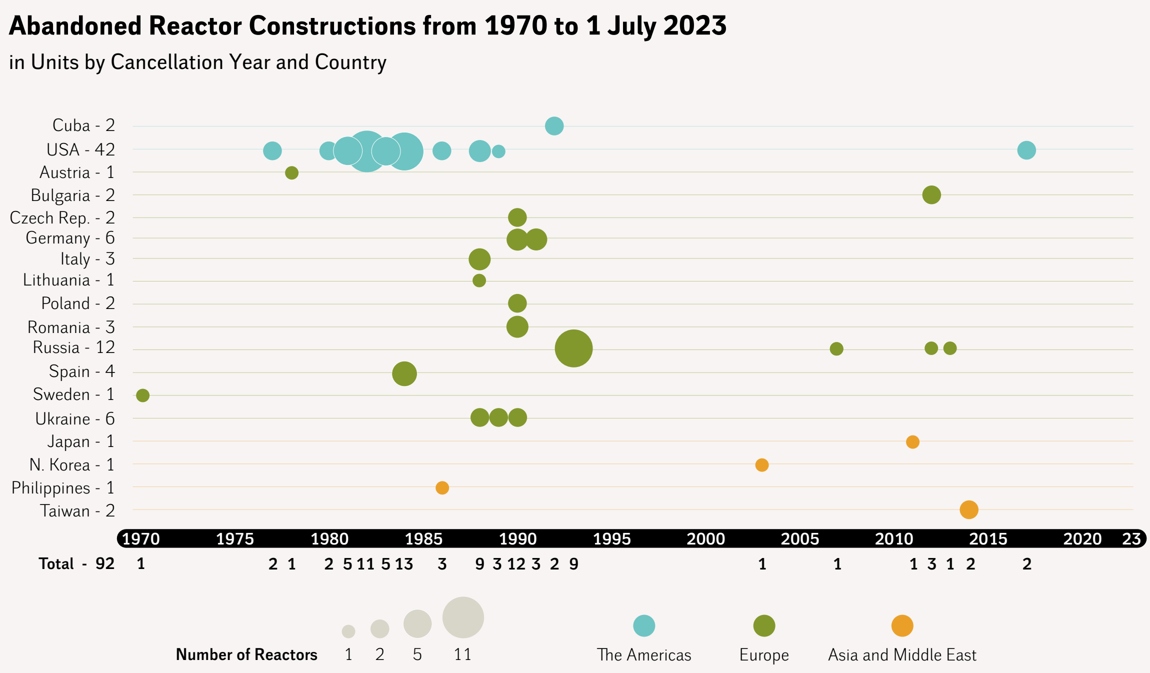
Sources: WNISR, with IAEA-PRIS, 2023

Experience shows that having an order for a reactor, or even having a nuclear plant at an advanced stage of construction, is no guarantee of ultimate grid connection and power production. The two V.C. Summer units, abandoned in July 2017 after four years of construction and following multi-billion-dollar investment, are only the latest in a long list of failed significantly advanced nuclear power plant projects.

French Alternative Energies & Atomic Energy Commission (CEA) statistics through 2002 indicate 253 "cancelled orders" in 31 countries, many of them at an advanced construction stage (see also Figure 17). The United States alone accounted for 138 of these order cancellations.[40]

40 - CEA, "Elecnuc—Nuclear Power Plants in the World", Commissariat à l'énergie atomique et aux énergies alternatives/French Alternatives Energies and Atomic Energy Commission, 2002. The section "cancelled orders" has disappeared after the 2002 edition.

Figure 17 · Cancelled or Suspended Reactor Constructions



Sources: WNISR, with IAEA-PRIS, 2023

Note: This graph only includes constructions that had officially started with the concreting of the base slab of the reactor building. Many more projects have been cancelled at earlier stages of construction/site preparation.

Of the 800 reactor constructions launched since 1951, at least 92 units in 18 countries had been abandoned or suspended, as of 1 July 2023. This means that 11.5 percent—or one in nine—of nuclear constructions have been abandoned.

Close to three-quarters (66 units) of all cancelled projects were in four countries alone—the U.S. (42), Russia (12), Germany and Ukraine (six each). Some units were 100-percent completed—including Kalkar in Germany and Zwentendorf in Austria—before it was decided not to operate them.

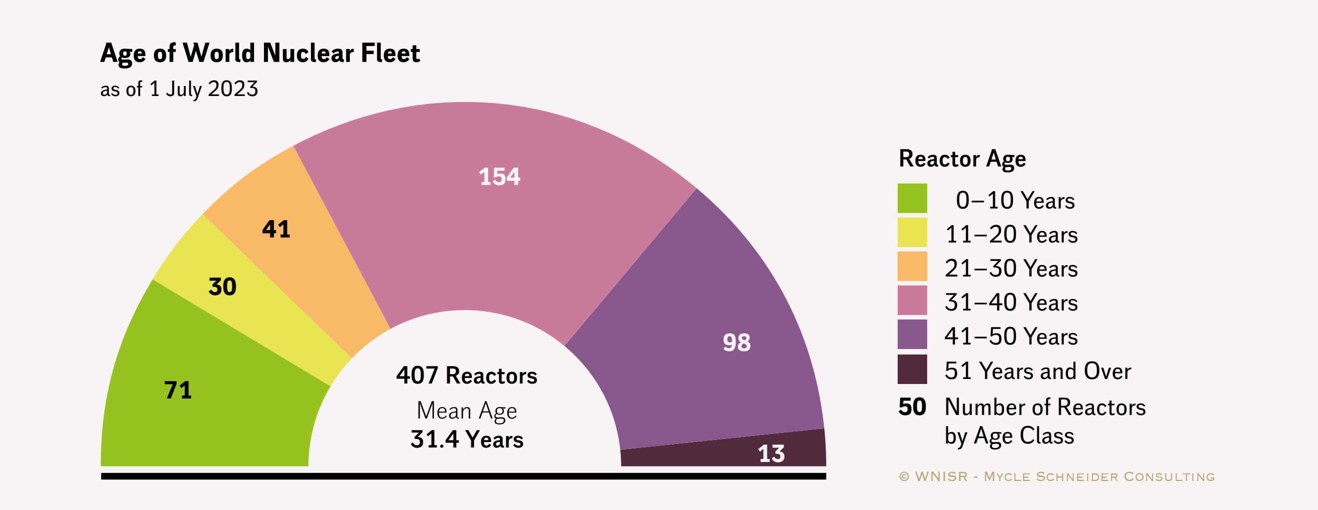
OPERATING AGE

In the absence of significant, successful newbuild over many years, the average age (from grid connection) of operating nuclear power plants has been increasing since 1984, and as of mid-2023 is 31.4 years, up from 31 years in mid-2022 (see Figure 18).[41]

A total of 265 reactors—five less than mid-2022—two-thirds of the world's operating fleet, have operated for 31 or more years, including 111—more than one in four—for at least 41 years.

41 - WNISR calculates reactor age from grid connection to final disconnection from the grid. In WNISR statistics, "startup" is synonymous with grid connection and "closure" with withdrawal from the grid. In order to have a better image of the fleet and ease calculations, the age of a reactor is considered to be 1 between the first and second grid connection anniversaries. For some calculations, we also use operating years: the reactor is in its first operating year until the first grid connection anniversary, when it enters the second operating year.

Figure 18 · Age Distribution of Operating Reactors in the World



Sources: WNISR, with IAEA-PRIS, 2023

In 1990, the average age of the operating reactors in the world was 11.3 years; in 2000, it was 18.8 years and it stood at 26.3 years in 2010. The leading nuclear nation also has the oldest reactor fleet of the top-five nuclear generators. The average age of reactors in the U.S. passed 40-years in 2020 and reached 42.1 years as of the end of 2022. France's fleet exceeded 37 years. Russia's fleet age peaked in 2017 and declined for a few years before increasing again starting in 2020 and its average fleet age of 29.4 years, as of the end of 2022, caught up with that of 2018. South Korea's reactors at 22.6 years remain almost half as old as the U.S. fleet, and China has an average fleet age of just 9.3 years. (See Figure 19).

Many nuclear utilities envisage average reactor lifetimes of beyond 40 years up to 60 and even 80 years. In the U.S., reactors are initially licensed to operate for 40 years, but nuclear operators can request a license renewal from the Nuclear Regulatory Commission (NRC) for an additional 20 years. An initiative to allow for 40-year license extensions in one step was terminated in June 2021 after NRC staff recommended that the Commission "discontinue the activity to consider regulatory and other changes to enable license renewal for 40 years."[42]

As of mid-2023, 84 of the 93 operating U.S. units had received a 20-year license extension, applications for three further reactors were under NRC review. The owners of three other reactors (Diablo Canyon-1 and -2, Clinton-1) plan to submit applications in late 2023 and early 2024. The Diablo Canyon units, scheduled to close when their current licenses expire in 2024–2025, might defer closure until 2029 and 2030.[43]

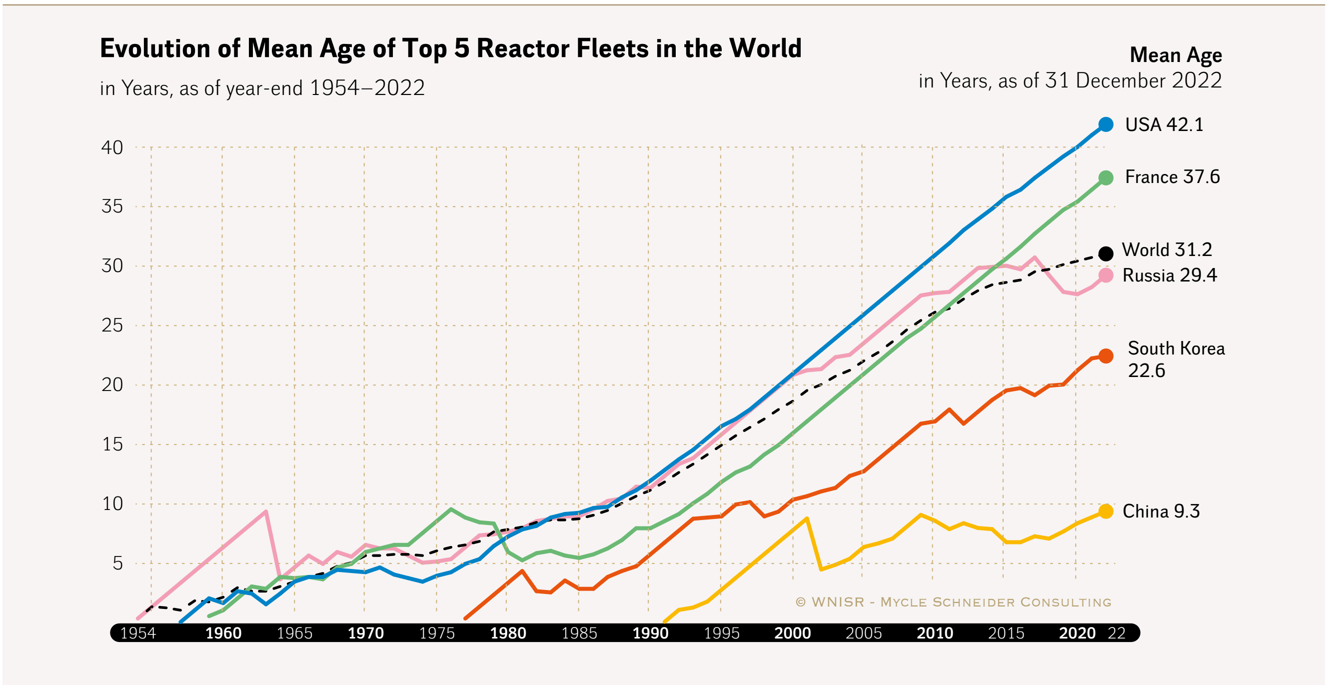
As of July 2023, the NRC had granted Subsequent Renewed Operating Licenses to six reactors, which permit operation from 60 to 80 years. However, the NRC effectively suspended four of these licenses in February 2022, while it develops a new environmental assessment for

42 - Division of New and Renewed Licenses, "Closure of Activity to Consider License Renewal for 40 Years of Additional Nuclear Power Plant Operation", Office of Nuclear Reactor Regulation, United States Nuclear Regulatory Commission, 22 June 2021, see https://www.nrc.gov/docs/ML2111/ML21117A007.pdf, accessed 11 August 2021.

43 - U.S. NRC, "Status of License Renewal Applications and Industry Activities", United States Nuclear Regulatory Commission, Updated 13 October 2023, see http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 7 November 2023.

subsequent license renewals. A further ten reactors have their applications still under review. See "Extended Reactor Licenses" in United States Focus for details and references.

Figure 19 • Reactor-Fleet Age of Top 5 Nuclear Generators



Sources: WNISR, with IAEA-PRIS, 2023

Only nine of the 41 units that have been closed in the U.S. had reached 40 years on the grid. All nine had obtained licenses to operate up to 60 years but were closed long before mainly for economic reasons. In other words, at least one quarter of the 134 reactors connected to the grid in the U.S. never reached their initial design lifetime of 40 years. Only one of those already closed had just reached 50 years of operation (Palisades, closed after 50.4 years). The mean age at closure of those 41 units was 22.8 years.

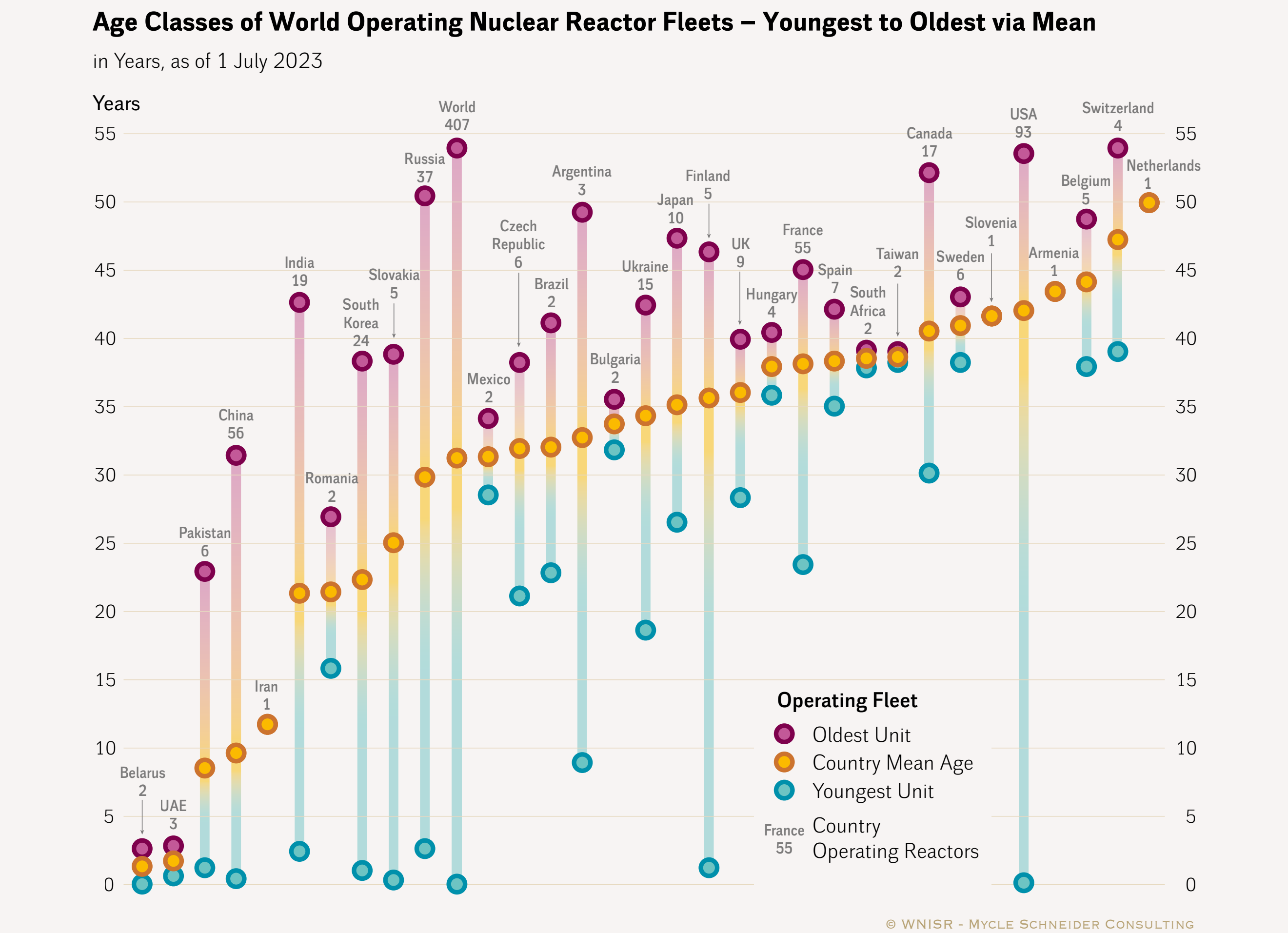
On the other hand, of the 93 currently operating plants, 49 units have already operated for 41 years, of which ten have been on the grid for 51 years or more; thus, over half of the units with license renewals have entered the lifetime extension period, and that share is growing rapidly with the mid-2023 mean age of the U.S. operational fleet exceeding 42.1 years (see United States Focus).

Many countries have no specific time limits on operating licenses. In France, for example, reactors must undergo in-depth inspection and testing every decade against reinforced safety requirements. The French reactors have operated for 38 years on average. The Nuclear Safety Authority (ASN) has evaluated each reactor, and most have been permitted to operate for up to 40 years, which is considered the limit of their initial design. However, the ASN assessments are years behind schedule. For economic reasons, the French state-controlled utility Électricité de France (EDF) prioritizes lifetime extension to 50 years over large-scale new-build.

EDF's approach to lifetime extension has been reviewed by ASN and its Technical Support Organization. In February 2021, ASN granted a conditional generic agreement to lifetime extensions of the 32 reactors of the 900 MW series. However, lifetime extensions beyond 40 years require reactor-specific licensing procedures involving public inquiries in France. For an assessment of the status of fourth decennial inspections see "Lifetime Extension – Fact Before License" in France Focus.

Recently commissioned reactors and the ones under construction in South Korea do or will have a 60-year operating license from the start. EDF will certainly also aim for 60-year operating licenses for its Flamanville-3 project and the Hinkley Point C units in the U.K.

Figure 20 · Age of World Nuclear Fleets



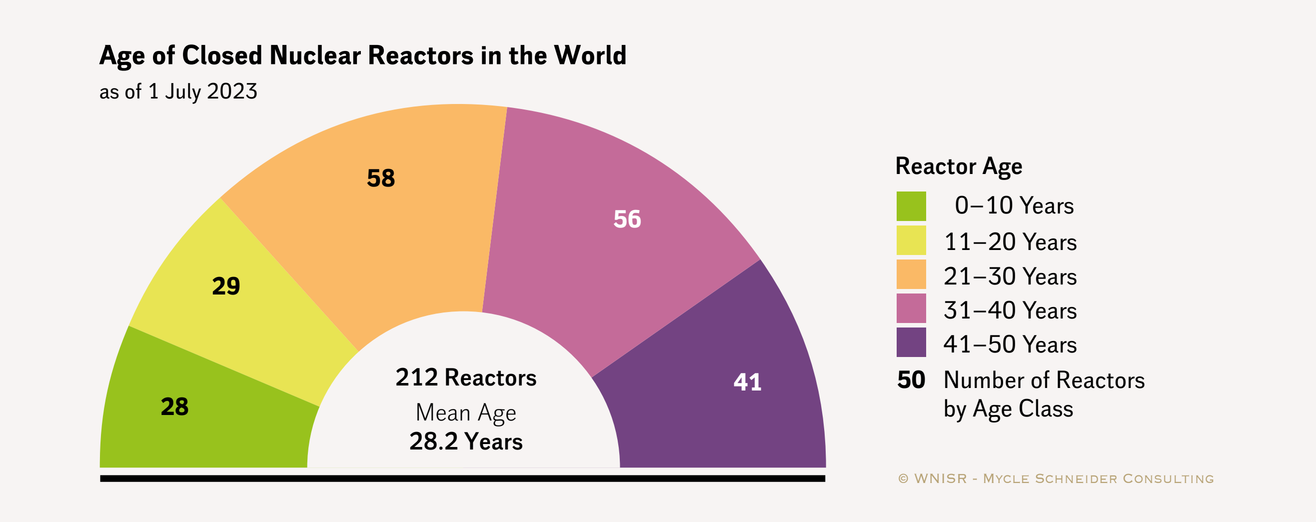
Sources: WNISR, with IAEA-PRIS, 2023

Note: This figure only takes into account reactors operating as of 1 July 2023, thus excluding reactors in LTO, in particular Tarapur-1 & -2 in India, that have passed 50 years.

Figure 20 shows that the average fleet age in 23 of the 32 countries that operate nuclear reactors as of mid-2023, is over 30 years, and in eight countries over 40. Over half, that is 19 of the countries have been operating one or more reactors for more than 40 years, but only five countries operate reactors that are over 50 years, while some others are approaching the milestone.

In assessing the likelihood of reactor fleets being able to operate for 50 or 60 years, it is useful to compare the age distribution of reactors that are currently operating with the 212 units that have already closed (see Figure 18 and Figure 21). In total, 97 of these units operated for 31 years or more, and, of those 97, 41 reactors operated for 41 years or more. Many units of the first-generation designs only operated for a few years. The mean age of the closed units is about 28 years.

Figure 21 • Age Distribution of Closed Nuclear Power Reactors

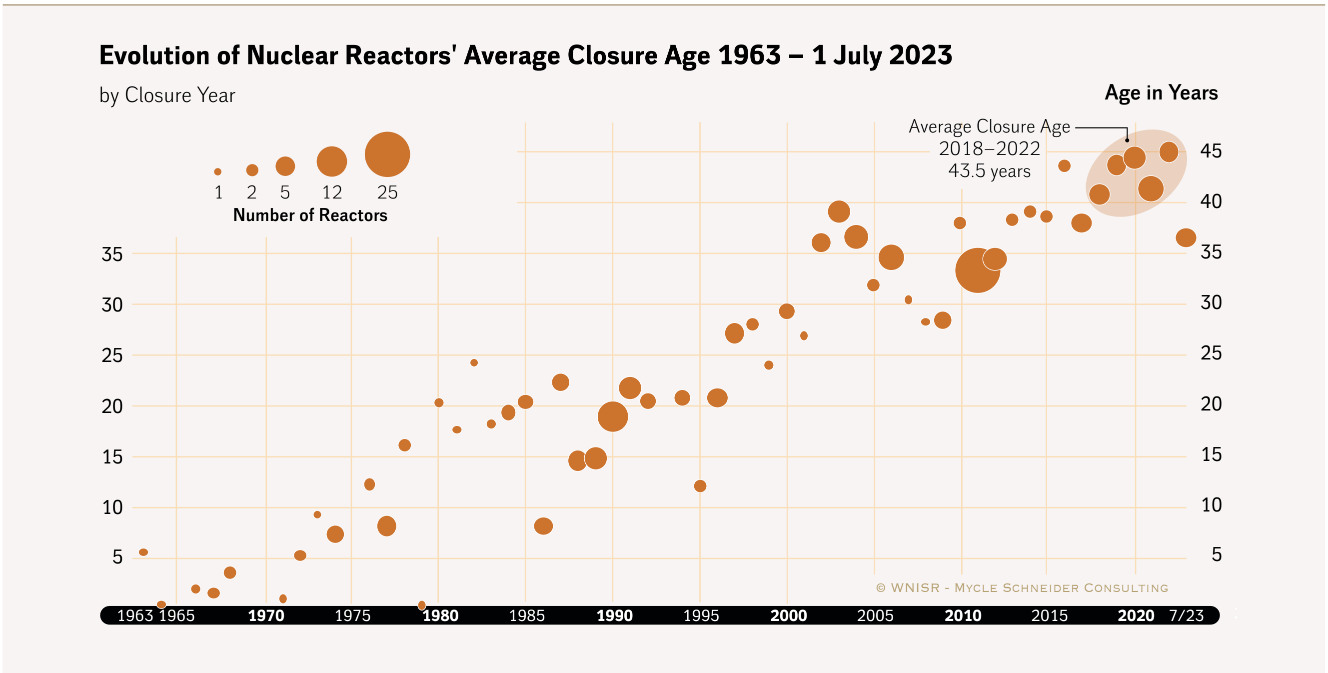


Sources: WNISR, with IAEA-PRIS, 2023

While the operating time prior to closure has clearly increased continuously, the mean age at closure of the 29 units taken off the grids in the five-year period between 2018 and 2022 was 43.5 years (see Figure 22).

As a result of the Fukushima nuclear disaster (elsewhere referred to as 3/11), many analysts have questioned the wisdom of operating older reactors. The Fukushima Daiichi units (1 to 4) were connected to the grid between 1971 and 1974. The license for Unit 1 had been extended for another 10 years in February 2011, just one month before the catastrophe began. Four days after the initial events in Japan, the German government ordered the closure of eight reactors that had started up before 1981, two of which were already closed at the time and never restarted. The sole selection criterion was operational age. Other countries did not adopt the same approach, but clearly the 3/11 events in Japan had an impact on previously assumed extended lifetimes in other countries. Some of the main nuclear countries closed their oldest units, at the time, before or long before age 50, including Germany at age 37, South Korea at 40, Sweden at 46, and the U.S. at 49. France closed its two oldest units in spring 2020 at age 43.

Figure 22 · Nuclear Reactor Closure Age



Sources: WNISR, with IAEA-PRIS, 2023

LIFETIME PROJECTIONS

Nuclear operators in many countries continue to implement or prepare for lifetime extensions. As in previous years, WNISR has created two lifetime projections. A first scenario (40-Year Lifetime Projection, see Figure 23), assumes a general lifetime of 40 years for worldwide operating reactors—not including reactors in Long-Term Outage (LTO).

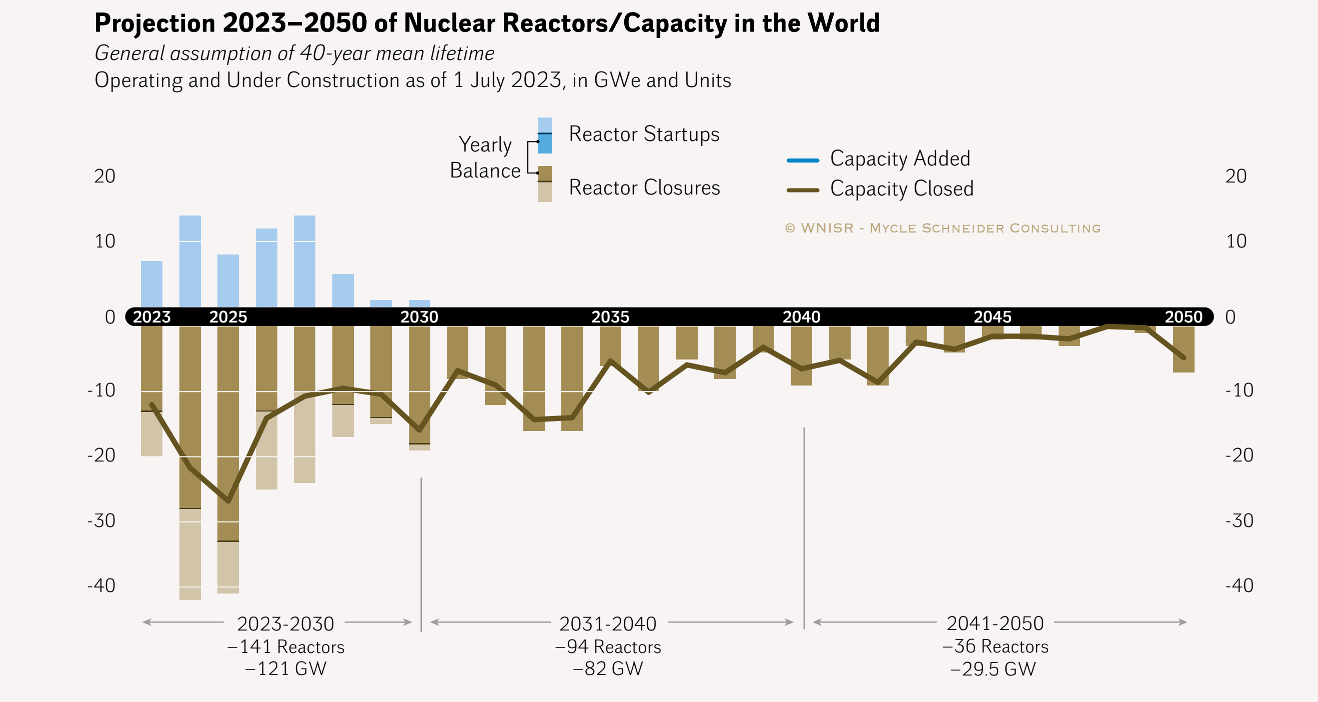
Forty years, explicitly or implicitly, corresponds to the design lifetimes of most operating reactors. Some countries have legislation or policy in place—including Belgium (even if the currently debated lifetime extension for two units was implemented), South Korea (in the course of being amended by the incoming administration) or Taiwan—that limit operating lifetime, for all or part of the fleet, to 40 or 50 years. Recent designs, mostly reactors under construction, have a design lifetime of 60 years (e.g. APR-1400, EPR). For the 122 reactors that have passed the 40-year lifetime as of mid-2023, we assume they will operate to the end of their licensed, extended operating time.

A second scenario (Plant Life Extension or PLEX Projection, see Figure 24) takes into account *all* already-authorized lifetime extensions as of mid-2023 and assumes that the respective reactors will operate until the expiration of their license—a very conservative assumption considering empirical evidence from the past.

The lifetime projections allow for an evaluation of the number of reactors and respective power generating capacity that would have to come online over the next decades to offset closures and simply maintain the same number of operating plants and level of capacity, if all units were closed after a lifetime of 40 years or after their licensed lifetime extension.

Considering all units under construction scheduled to have started up, 13 additional reactors (compared to the end of 2022 status) would have to be commissioned or restarted prior to the end of 2023 in order to maintain the status quo of operating units. Without additional startups, installed nuclear capacity would decrease by 12 GW by the end of 2023.

Figure 23 · The 40-Year Lifetime Projection



Sources: Various, compiled by WNISR, 2023

Notes pertaining to Figure 23, Figure 24 and Figure 25:

Those figures include one Japanese reactor (Shimane), two Chinese 1400 MW-units at Shidao Bay and two Russian 55 MW RITM reactors, for which the startup dates were arbitrarily set to 2025, 2024 and 2027, as there are no official dates.

Restarts or closures amongst the 31 reactors in LTO as of 1 July 2023 are not represented in Figure 23 and Figure 24, although at least two Canadian, two Japanese and one French reactors that were in LTO have restarted since, and will thus be later closed as well. Those are counted as "operating" in Figure 25 (under the criteria of the PLEX projection).

The figures take into account current political decisions or legally binding obligations as of end of July 2023 to close reactors prior to 40 years (South-Korea). These decisions are under discussions and might be reversed after the editorial deadline of WNISR2023, as is the case in Belgium, with discussions on a ten-year lifetime extension for two reactors beyond the current license expiration in 2025.

In the case of reactors that have reached 40 years of operation prior to 2023, the 40-year projection also uses the end of their licensed lifetime (including 6 reactors licensed for 80 years in the U.S., even though the licenses of four of these units have been suspended).

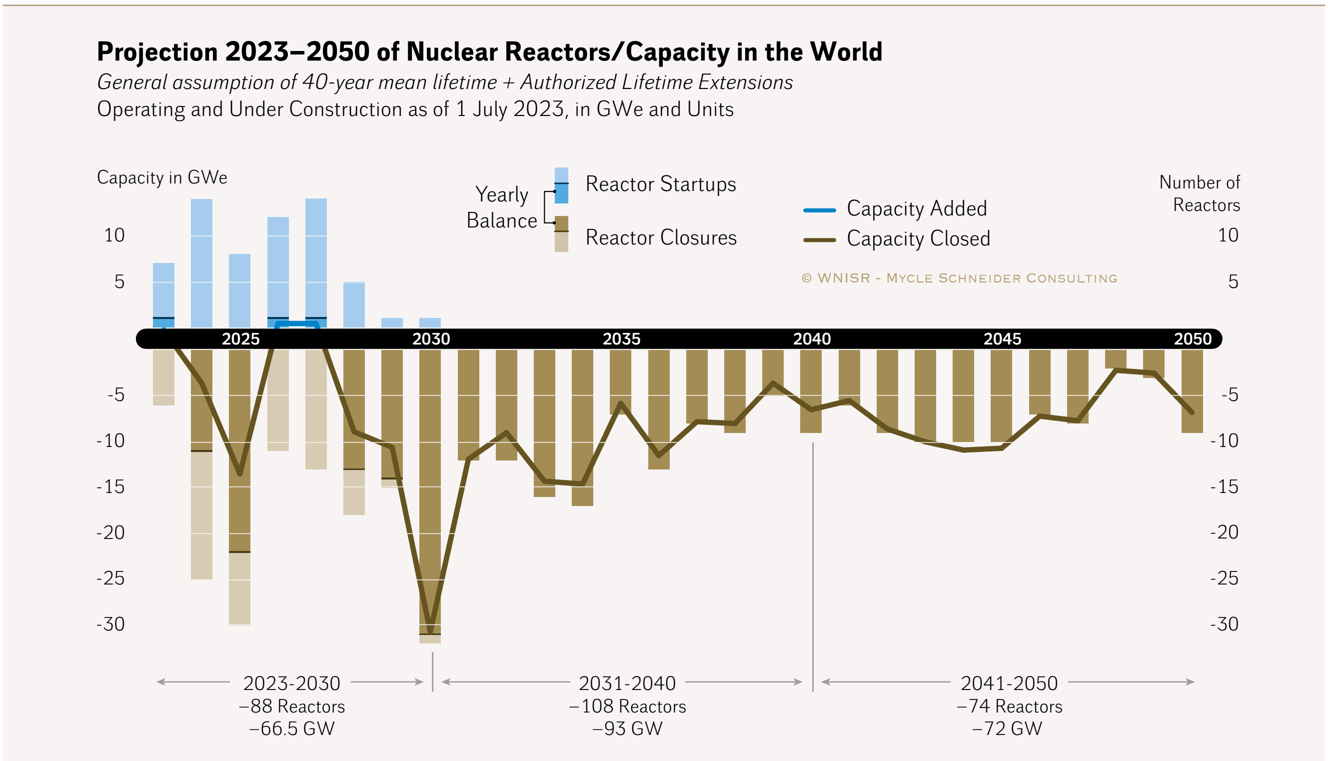
In the case of French reactors that have reached 40 years of operation prior to 2023 (startup before 1983), we use the deadline for their 4th periodic safety review (visite décennale) as closing date in the 40-year projection. In case this deadline is or will be passed by the end of 2023 (10 reactors), we use a 10-year extension, although no licensing procedure has been completed for this extension besides Tricastin-1. For all those that have already passed their 3rd periodic safety review, the scheduled date of their 4th periodic safety review (or 10-year extension for the cases previously mentioned) is used in the PLEX projection, regardless of their startup date.

In the remaining years to 2030, in addition to the units currently under construction, 141 new reactors (121 GW)—over 17 units or 15 GW per year—would have to be connected to the grid to maintain the status quo, almost three times the rate achieved over the past decade (66 startups between 2013 and 2022, that is 6.6 units or 6.5 GW per year).

The relative stabilization of the situation by the end of 2023 is only possible because most reactors will likely not close, regardless of their age. The number of reactors in operation will probably continue to stagnate at best, unless—beyond restarts—lifetime extensions become the rule worldwide. Such generalized lifetime extensions—far beyond 40 years—are clearly the objective of the international nuclear power industry, and, especially in the U.S., there are numerous attempts to obtain subsidies for uneconomic nuclear plants in order to keep them on the grid (see Securing Subsidies to Prevent Closures in United States Focus).

Developments in Asia, including in China, do not fundamentally change the global picture. Reported ambitions for China's targets for installed nuclear capacity have fluctuated in the past. While construction starts have picked up speed again in 2021–2022, Chinese medium-term ambitions appear significantly lower than anticipated in the pre-3/11 era.[44]

Figure 24 · The PLEX Projection (not including LTOs)



Sources: Various, compiled by WNISR, 2023

Notes: see Figure 23.

Every year, WNISR also models a scenario in which all currently licensed lifetime extensions and license renewals are maintained, and all construction sites are completed. For all other units, we have maintained a 40-year lifetime projection, unless a firm earlier or later closure date has been announced. By the end of 2023, the net number of operating reactors and operating capacity would remain almost stable (+ 1 unit / - 0.3 GW).

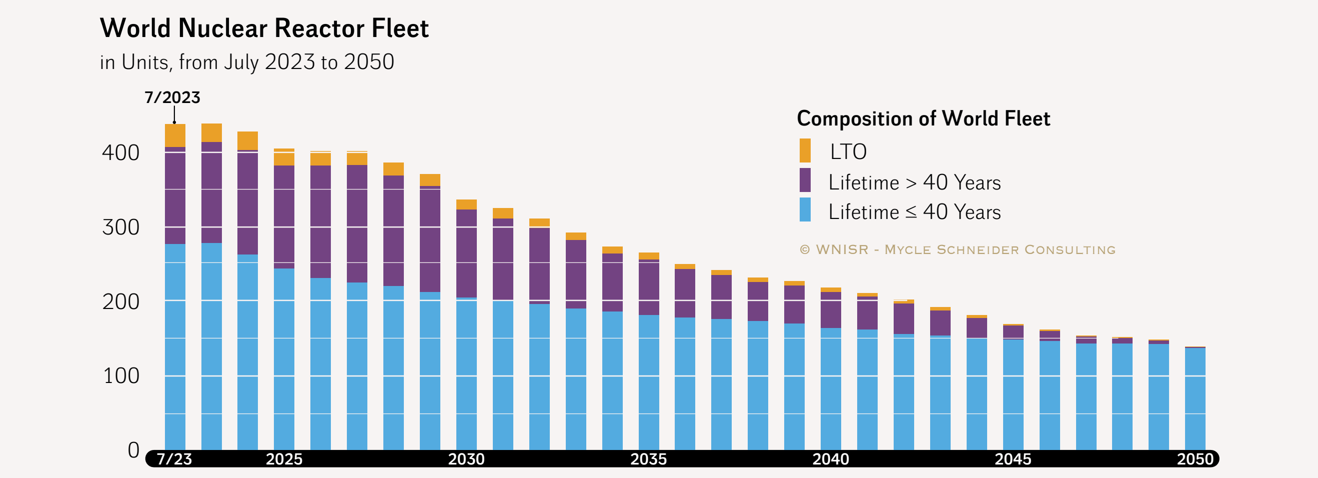
44 - As of early November 2023, only three construction starts had taken place in China since the beginning of the year. Worldwide only one more reactor building started (in Egypt, implemented by Russia).

In the remaining years to 2030, the net balance would turn negative as soon as 2024, and slightly positive for the years 2026–2027 but overall, an additional 88 new reactors (66.5 GW)—almost one unit or 0.7 GW per month—would have to start up or restart to replace closures.

The PLEX-Projection would still mean for the remaining years to 2030, a need to almost double the annual startup rate of the past decade from six to eleven units (see Figure 23, Figure 24 and the cumulated effect in Figure 25).

However, as documented in detail above, construction starts have not been picking up over the past decade. Between 2013 and 2017, a total of 29 constructions were launched around the world, of which 12 in China and two later abandoned in the U.S. Between 2018 and 2022, constructions started at 36 units, of which 19 in China, thus an average of 6.5 units per year were launched and sustained so far, hardly an increase over the past and hardly more than half of the startup rate needed according to the PLEX Projection over the remaining years to 2030 just to maintain the current number of operating reactors in the world.

Figure 25 • Forty-Year Lifetime Projection versus PLEX Projection



Sources: Various, compiled by WNISR, 2023

Notes: This figure illustrates the trends, and the projected composition of the current world nuclear fleet, taking into account existing reactors (operating and in LTO) and their closure dates (40-years Lifetime vs authorized Lifetime Extension) as well as the 58 reactors under construction as of 1 July 2023.

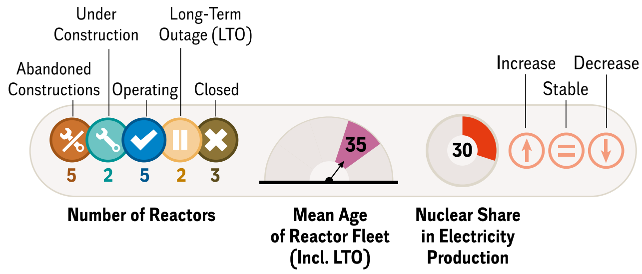
The graph does *not* represent a forecasting of the world nuclear fleet over the next three decades as it does not speculate about future constructions.

This figure takes into account the restarts of Bruce-6, Darlington-3, Penly-1, Takahama-1 &-2 during the second half-year of 2023.

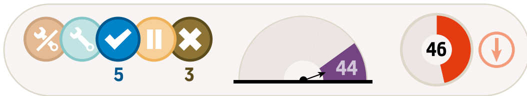
Further detail, see Figure 23.

FOCUS COUNTRIES

These "quick view" indicators will be used in the country sections throughout the report.



BELGIUM FOCUS



After a decade of ups and downs due to multiple technical issues and a record nuclear production of 48 TWh in 2021, nuclear generation dropped by 13 percent in 2022 to 41.7 TWh.

In 2022, Belgium operated seven pressurized water reactors (PWRs) on the Tihange and Doel sites that contributed 46.4 percent of Belgium's electricity, a 4.4 percentage-point drop over 2021. The historic maximum nuclear share was 67.2 percent in 1986.

In the framework of the Belgian nuclear phaseout legislation, the nuclear operator closed Doel-3 on 23 September 2022 and Tihange-2 on 31 January 2023. The average age of the Belgian fleet is 44.2 years.

Belgium remains highly dependent on fossil fuels as contributions to final energy consumption in 2022 represented 47.2 percent for oil, 24.6 percent of natural gas (together 71,8 percent) with nuclear at 8.4 percent and renewables at only 7 percent.[45]

The gas-price increase in the fall of 2021 and the war in Ukraine have reopened the debate about the possibility of lifetime extension of the two most recent units, Tihange-3 and Doel-4, and the government has introduced corresponding preliminary legislative proposal on 1 April 2022. However, as of mid-October 2023, no new legislation had been approved, there is no final binding contractual agreement between the Government and the operator, while there is no longer a debate about potential lifetime extensions of the remaining three of the seven Belgian reactors beyond the closure schedule specified by current law.

Legally the country remains bound to a nuclear phase-out target of 2025. In January 2003, legislation was passed that requires the closure of all of Belgium's nuclear plants after 40 years of operation, so based on their startup dates, plants would have been closed progressively between 2015 and 2025 (see Table 4). Practically, however, after lifetime extension to 50 years was granted for three reactors, five of the seven reactors would have gone offline in the single year of 2025. The planned buildup of alternative power generation capacity had not taken into account the energy crisis and following constraints on the natural gas market. The lifetime extension option gained momentum, long and complex negotiations followed.

45 - SPF Economie, "Belgian Energy Data Overview", Service Public Fédéral Economie/Federal Public Service Economy, SMEs, Self-Employed and Energy, Updated 4 July 2023 (in French), see https://economie.fgov.be/fr/publications/belgian-energy-data-overview, accessed 18 October 2023.

Table 4 · Belgian Nuclear Fleet (as of 1 July 2023)

Reactor	Net Capacity (MW)	Grid Connection	Operating Age (as of 1 July 2023)	End of License (Closure Date)
Doel-1	433	28/08/1974	48.8	10-year lifetime extension to 15 February 2025
Doel-2	433	21/08/1975	47.9	10-year lifetime extension to 1 December 2025
Doel-3	1 006	23/06/1982		1 October 2022 (Closed on 23 September 2022)
Doel-4	1 038	08/04/1985	38.2	1 July 2025
Tihange-1	962	07/03/1975	48.3	10-year lifetime extension to 1 October 2025
Tihange-2	1 008	13/10/1982		1 February 2023 (Closed on 31 January 2023
Tihange-3	1 038	15/06/1985	38.0	1 September 2025

Sources: Belgian Law of 28 June 2015[46], WNISR various.

Lifetime Extension of Tihange-3 and Doel-4?

Operator Electrabel, a subsidiary of French energy group Engie, had previously signaled that it was interested in extending the lifetime of two or three units beyond 2025 but warned that it would need legislation to be adapted by the end of the year 2020.[47] This did not happen and Engie decided "to stop preparation works that would allow for the 20-year extension of two nuclear units beyond 2025".[48]

In July 2022, the Belgian government inquired whether Tihange-2, slated for closure on 1 February 2023, could be kept operating until the end of March 2023. Engie stated that a lifetime extension of Tihange-2 "had never been on the table" and that on such short notice, without any preparatory work having been done, "it is not possible due to both technical and nuclear safety constraints".[49] In another statement Engie explained that any lifetime extension of Tihange-2 was "not an option" and pointed out that "taking into account the concrete situation, considering such a scenario in haste, without the necessary preliminary studies having been carried out, is not possible with regard to the imperatives of nuclear safety (...)".[50] Accordingly, Tihange-2 was closed on 31 January 2023.

46 - *Moniteur Belge*, "Loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l'énergie nucléaire à des fins de production industrielle d'électricité afin de garantir la sécurité d'approvisionnement sur le plan énergétique", N.174, Second Edition, 6 July 2015 (in French and Dutch), see http://www.ejustice.just.fgov.be/mopdf/2015/07/06_2.pdf.
- For Doel-1&-2, see Electrabel, GDF Suez/Engie, "Note de Presse—Sécurité d'approvisionnement et transition énergétique—Accord sur la prolongation de Doel 1 et Doel 2", Press Release,1 December 2015 (in French) and Engie Electrabel, "Doel Nuclear Power Plant—Profile of the 4 units", Updated 7 August 2017, see http://corporate.engie-electrabel.be/local-player/nuclear-3/doel/;
- For Tihange-1, see Engie/Electrabel, "Tihange", Undated, see http://corporate.engie-electrabel.be/local-player/nuclear-3/tihange/; all accessed 23 June 2019.

47 - Herman Moestue, "Electrabel réitère son appel à prolonger le nucléaire belge", *Montel*, 28 January 2020 (in French), see http://www.montelnews.com/fr/story/electrabel-ritre-son-appel-à-prolonger-le-nuclaire-belge/1082410, accessed 8 August 2020.

48 - Engie, "2020 Management Report and Annual Consolidated Financial Statements", March 2021, see https://www.engie.com/sites/default/files/assets/documents/2021-02/ENGIE_2020_Management_report_and_annual_consolidated_financial_statements.pdf, accessed 1 August 2021.

49 - *WNN*, "Belgium asks Engie to extend Tihange 2's life", *World Nuclear News*, 18 July 2022, see https://www.world-nuclear-news.org/Articles/Belgium, accessed 24 July 2022.

50 - *RTBF*, "Sortie du nucléaire : prolonger Tihange 2 deux mois ? Engie dit non au gouvernement", 16 July 2022 (in French), see https://www.rtbf.be/article/sortie-du-nucleaire-prolonger-tihange-2-deux-mois-engie-dit-non-au-gouvernement-11032081, accessed 21 August 2022.

In the fall of 2021, pressure increased to reassess the potential lifetime extension of Tihange-3 and Doel-4, and in January 2022, the Federal Agency for Nuclear Control (FANC) issued a report commissioned by the government concluding a lifetime extension "would be possible from a nuclear safety point of view but only if the facilities were updated".[51]

On 16 July 2022, Tinne Van der Straeten, Minister for Energy, stated in an interview: "The biggest concern is France, which is experiencing the largest unavailability of its nuclear fleet in its history. (…) We are not sure we will be able to import as much electricity as expected from France." Belgium has been however a net power exporter over the year since 2019. The minister confirmed that the operation of Doel-3, slated for closure by 1 October 2022, could not be extended due to a lack of fuel.[52]

On 22 July 2022, the government signed a "non-binding declaration of intent" with Engie to "evaluate the feasibility and the conditions of a [license] renewal of the two most recent reactors", Tihange-3 and Doel-4, for a 10-year period starting in November 2026. Engie, that had reoriented corporate strategy away from nuclear, is requesting stiff conditions for a deal. While Engie would remain the operator, the Belgian state would enter a joint company and provide half of the capital. In addition, decommissioning and waste management costs—for all seven reactors—should be determined in a study and would then be capped.[53] A final agreement was to be negotiated by the end of the year 2022. That did not happen. Instead, on 9 January 2023, the government—represented by the Prime Minister and the Green Party Energy Minister—jointly announced the signature of a "Heads of Terms and Commencement of LTO [Long-Term Operation] Studies Agreement" with Engie, stating that

> This agreement in principle constitutes an important step, and paves the way for the conclusion of full agreements in the upcoming months. It also provides for the immediate start of environmental and technical studies prior to obtaining the authorizations related to this extension. (…)
>
> With this agreement, both parties confirm their objective to make reasonable endeavours to restart the Doel 4 and Tihange 3 nuclear units in November 2026.[54]

Green-Party Co-President Rajae Maouane commented : "I'm part of this new generation of environmentalists for whom nuclear power is no longer a taboo."[55]

51 - AFCN/FANC, "Sortie du nucléaire : l'AFCN soumet son rapport au gouvernement fédéral—Possible prolongation d'exploitation en toute sûreté de Doel 4 et Tihange 3, sous conditions", Agence Fédérale de Contrôle Nucléaire/Federal Agency for Nuclear Control, Press Release (in French), 17 January 2022, see https://afcn.fgov.be/fr/actualites/sortie-du-nucleaire-lafcn-soumet-son-rapport-au-gouvernement-federal, accessed 3 August 2022.

52 - Christine Scharff and Maxime Vande Weyer, "Tinne Van der Straeten, ministre fédérale de l'Énergie: 'Nous sommes en situation de guerre'", *L'Echo*, Interview with Tinne Van der Straeten, Belgian Minister of Energy (in French), 16 July 2022, see https://www.lecho.be/economie-politique/belgique/federal/tinne-van-der-straeten-ministre-federale-de-l-energie-nous-sommes-en-situation-de-guerre/10402151.html, accessed 30 August 2022.

53 - Miguel Allo, "Accord de principe entre le gouvernement fédéral et Engie en vue de prolonger l'exploitation des réacteurs nucléaires Doel 4 et Tihange 3", *RTBF*, 22 July 2022 (in French), see https://www.rtbf.be/article/accord-de-principe-entre-le-gouvernement-federal-et-engie-en-vue-de-prolonger-lexploitation-des-reacteurs-nucleaires-doel-4-et-tihange-3-11035702, accessed 21 August 2022.

54 - ENGIE, "ENGIE and the Belgian federal government set a frame for the extension nuclear reactors of Doel 4 and Tihange 3", Press Release, 9 January 2023, see https://nuclear.engie-electrabel.be/en/press/release/engie-and-belgian-federal-government-set-frame-extension-nuclear-reactors-doel-4-and, accessed 25 October 2023.

55 - David Coppi, "'Dire que le contribuable paiera la prolongation du nucléaire, c'est totalement faux'", Interview with Jean-Marc Nollet and Rajae Maouane, Co-Presidents, Ecolo/Belgian Green Party (in French), *Le Soir*, 14 January 2023.

Between 20 March and 20 June 2023, the Belgian government held a transboundary public consultation on the basis of the "Environmental Impact Assessment in the context of postponing the deactivation of the Doel 4 and Tihange 3 nuclear power plants".[56]

According to ENGIE, the intermediate agreement signed with the Belgian government on 29 June 2023, only nine days after the end of the public consultation, contains the following key points:[57]

- "The commitment from both parties to use their best efforts to restart the nuclear units of Doel 4 and Tihange 3 as early as November 2026, or, subject to the effective implementation of an announced relaxation of regulations, as early as November 2025, with the aim to strengthen the security of supply in Belgium."
- The Doel-4 and Tihange-3 reactors will be co-owned in a 50-50 percent partnership.
- The remuneration will be based on a Contract for Difference model.
- ENGIE will pay a lump sum of €15 billion (US$16 billion) for "the future costs of nuclear waste management" of all seven of ENGIE's nuclear reactors in Belgium. The amount is to be paid in two instalments, one at closing in the first semester 2024 for intermediate- and high-level nuclear waste, and a second payment in 2026 for low-level waste.
- Electrabel has already ordered fuel and the nuclear regulator has determined the scope of inspections and work to be carried out for the operation of ten additional years.

That agreement was followed by another "intermediate agreement" signed on 21 July 2023[58] and to be followed by the final, legally binding agreement by the end of October 2023 (but had not been announced as of 31 October 2023), which then must be approved by the European Commission. Closure of the deal is expected in the first half of 2024.[59]

On 20 July 2023, the Federal Agency for Nuclear Control (FANC) communicated its expectations to ENGIE Electrabel to allow for the lifetime extensions beyond 2025. The regulator proposes to stagger upgrading work to 2028 to allow for the two reactors to be available during the winters 2025–2026 and 2026–2027. ENGIE Electrabel now has to come up with concrete proposals on how and by when to implement the requested upgrading work.[60]

56 - FPS Economy, "Public consultation on the life extension of Doel 4 and Tihange 3", Federal Public Service Economy, May 2023, see https://economie.fgov.be/en/themes/energy/public-consultation-life, accessed 8 June 2023; and SCK CEN, "Non-technical summary of the Environmental Impact Assessment In the context of postponing the deactivation of the Doel 4 and Tihange 3 nuclear power plants", Studiecentrum voor kernenergie/Centre d'étude de l'énergie nucléaire/Belgian Nuclear Research Centre, 20 March 2023.

57 - ENGIE, "ENGIE signs an agreement with the Belgian government on the extension of Tihange 3 and Doel 4 nuclear reactors and all obligations related to nuclear waste", Press Release, 29 June 2023, see https://corporate.engie.be/en/press/release/engie-signs-agreement-belgian-government-extension-tihange-3-and-doel-4-nuclear, accessed 21 July 2023; and ENGIE Electrabel, "What was agreed between ENGIE and the Belgian government on the 10-year operating extension of Doel 4 and Tihange 3?", Undated, see https://nuclear.engie-electrabel.be/en/nuclear-energy/key-questions-about-nuclear-power-plants/what-was-agreed-between-engie-and-belgian, accessed 31 October 2023

58 - ENGIE Electrabel, "Signing of Framework Agreement with the Belgian state", 21 July 2023, see https://nuclear.engie-electrabel.be/en/news/signing-framework-agreement-belgian-state, accessed 1 November 2023.

59 - ENGIE Electrabel, "What was agreed between ENGIE and the Belgian government on the 10-year operating extension of Doel 4 and Tihange 3?", Undated, op. cit.; and ENGIE, "ENGIE signs an agreement with the Belgian government on the extension of Tihange 3 and Doel 4 nuclear reactors and all obligations related to nuclear waste", Press Release, 2023, op. cit.

60 - AFCN/FANC, "L'AFCN envoie ses exigences de sûreté à ENGIE Electrabel pour la prolongation de Doel 4 et Tihange 3", Agence fédérale de Contrôle nucléaire/Federal Agency for Nuclear Control of Belgium, 20 July 2023 (in French), see https://afcn.fgov.be/fr/actualites/lafcn-envoie-ses-exigences-de-surete-engie-electrabel-pour-la-prolongation-de-doel-4-et, accessed 21 July 2023.

Many technical and legal challenges remain to be solved prior to the operation of Doel-4 and Tihange-3 beyond 2025. In February 2023, ENGIE has ruled out the lifetime extension of the three other remaining operating reactors Doel-1 and -2, and Tihange-1 calling the option "unthinkable".[61] In March 2023, FANC ruled out the prolongation option for the three units on safety grounds.[62]

Previous Lifetime Extensions

In summer 2012, the operator identified an unprecedented number of hydrogen-induced crack indications in the pressure vessels of Doel-3 and Tihange-2, with respectively over 8,000 and 2,000 previously undetected defects, which later increased to over 13,000 and over 3,000. In spite of widespread concerns, and although no failsafe explanation about the negative initial test results was given, on 17 November 2015, FANC authorized the restart of Doel-3 and Tihange-2 (see previous WNISR editions for details).

The Belgian government did not wait for the outcome of the Doel-3/Tihange-2 issue and decided in March 2015 to draft legislation to extend the lifetime of Doel-1 and Doel-2 by ten years to 2025. The law went into effect on 6 July 2015. On 22 December 2015, FANC authorized the lifetime extension and restart of Doel-1 and -2.[63]

On 6 January 2016, two Belgian NGOs filed a complaint against the 28 June 2015 law with the Belgian Constitutional Court, arguing in particular that the lifetime extension had been authorized without a legally required public enquiry. Following a 22 June 2017 pre-ruling decision, the Court addressed a series of questions to the European Court of Justice (ECJ), in particular concerning the interpretation of the Espoo and Aarhus Conventions, as well as the European legislation.[64]

On 29 July 2019, the ECJ stated that the lifetime extension of a reactor

> must be regarded as being of a comparable scale, in terms of risks of environmental impact, to the initial commissioning of those power stations. Consequently, it is mandatory for such a project to be the subject of an environmental impact assessment provided for by the EIA directive.[65]

61 - *L'Echo*, "Prolongation du nucléaire: la piste Doel 1, Doel 2 et Tihange 1 enterrée?", 28 February 2023 (in French), see https://www.lecho.be/dossiers/crise-energetique/prolongation-du-nucleaire-la-piste-doel-1-doel-2-et-tihange-1-enterree/10450477.html, accessed 31 October 2023.

62 - *NEI Magazine*, "Belgian regulator opposes life extension of oldest reactors", *Nuclear Engineering International*, 9 March 2023, see https://www.neimagazine.com/news/newsbelgian-regulator-opposes-life-extension-of-oldest-reactors-10660623, accessed 9 March 2023

63 - AFCN/FANC, "Exploitation à long terme (LTO) des centrales nucléaires belges - 2015", Agence fédérale de Contrôle nucléaire/ Belgian Federal Agency for Nuclear Control, Updated 18 January 2022 (in French), see https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/exploitation-long-terme-lto-des-centrales-nucleaires, accessed 30 August 2022.

64 - Cour Constitutionnelle, "Request for a preliminary ruling from the Cour constitutionnelle (Constitutional Court, Belgium) lodged on 7 July 2017 — Inter-Environnement Wallonie asbl, Bond Beter Leefmilieu Vlaanderen vzw v Conseil des ministers—Case C-411/17"", Constitutional Court of Belgium, *Official Journal of the European Union, 11 September 2017, see* https://eur-lex.europa.eu/legal-content/en/TXT/PDF/?uri=uriserv%3AOJ.C_.2017.300.01.0022.01.ENG, accessed 3 November 2023.

65 - ECJ, "The Belgian law extending the operating life of nuclear power stations Doel 1 and Doel 2 was adopted without the required environmental assessments being carried out first—Judgment in Case C-411/17", Press Release No 100/19, Court of Justice of the European Union, 29 July 2019, see https://curia.europa.eu/jcms/upload/docs/application/pdf/2019-07/cp190100en.pdf, accessed 30 August 2022.

In addition, as the Doel-1 and -2 reactors are particularly close to the Belgian-Dutch border, “such a project must also be subject to the transboundary assessment procedure”. The judgement permitted to delay the implementation of the order, if a national court considers it is

> justified by overriding considerations relating to the need to exclude a genuine and serious threat of interruption to the electricity supply in the Member State concerned, which cannot be addressed by other means or alternatives, inter alia in the context of the internal market. [Considers t]hat maintenance may only last for the amount of time strictly necessary in order to remedy that illegality.[66]

On 5 March 2020, the Belgian Constitutional Court nullified the lifetime extension legislation in its entirety but gave the government until the end of 2022 “at the latest” to carry out an appropriate Environmental Impact Assessment (EIA) and a transboundary consultation.[67]

The Belgian government argued that the lifetime extension “plays a vital role in securing its supply of electricity until 2025” and sent a notification for consultation to a number of European governments inviting them to comment on the “project” (that is the well engaged lifetime extension of Doel-1 and -2).[68]

The Belgian precedent has significant consequences on lifetime extension projects in European Union Member States that now will all have to carry out full-scale EIAs and organize transboundary consultations prior to granting permission for lifetime extensions.

National Energy and Climate Policy

The National Energy and Climate Plan (Plan National Énergie-Climat or PNEC) was passed in late 2019 and defines the strategy of compensation for the 6 GW of nuclear power that would have been closed by the end of 2025. A capacity market shall attract the necessary investments into other generation capacity and flexibility options. The renewable energy target is set at 40 percent by 2030. The interconnection with neighboring countries, already on a high level, will be further improved.[69]

Part of the nuclear phase-out strategy was the buildup of offshore wind capacities. In 2020, Belgium reached 2.3 GW installed capacity.[70] Offshore wind development shall continue with the designation of a second zone in the North Sea that will see the first turbines connected to the grid in 2027–2028 and ultimately add 3.1–3.5 GW to the national fleet.[71]

66 - Ibidem.

67 - Cour Constitutionnelle, “La Cour annule la loi qui prolonge l’activité des centrales nucléaires de Doel 1 et 2, en l’absence d’études préalables d’incidences environnementales, mais en maintient les effets jusqu’au plus tard le 31 décembre 2022” , Press Release (in French), Constitutional Court, 5 March 2020 see https://www.const-court.be/public/f/2020/2020-034f-info.pdf; for the text of the judgement (in French) see Cour Constitutionnelle, “Arrêt 34/2020”, Constitutional Court, 5 March 2020, see https://www.const-court.be/public/f/2020/2020-034f.pdf, both accessed 30 August 2022.

68 - Marie-Christine Marghem, Letter dated 13 August 2020, Ministry of Energy, Environment and Sustainable Development, Belgium.

69 - National Energy and Climate Plan, “PNEC 2021 – 2030—version définitive” and “NEKP 2021 – 2030—definitieve versie”, approved on 18 December 2019 (in French and Dutch), see https://www.nationalenergyclimateplan.be/en/what-is-the-necp-#the-final-plan, accessed 30 August 2022.

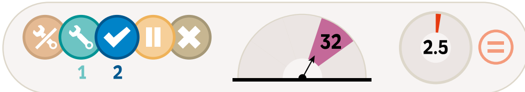
70 - BOP, “First offshore wind energy zone in the Belgian North Sea fully and on time completed”, Belgian Offshore Platform, 3 January 2021, see https://www.belgianoffshoreplatform.be/en/news/first-offshore-wind-energy-zone-in-the-belgian-north-sea-fully-and-on-time-completed/, accessed 1 August 2021.

71 - SPF Economie, “Belgian Energy Data Overview”, 2023, op. cit.

In 2022, a year with exceptionally low wind speeds, offshore wind farms generated 6.7 TWh (gross) compared to 5.3 TWh (gross) for onshore turbines, providing together about as much energy as in 2021 and just over half of the renewable contribution to overall electricity production. Solar electricity generation increased by a remarkable 25.7 percent to 7.1 TWh.

Cumulated installed generating capacity of wind and solar reached 11.7 GW or just over 45 percent of total electricity. All renewable energies combined generated 23.7 TWh (gross) or 24.9 percent, more than natural gas plants with 22.2 TWh (gross) or 23.4 percent.[72]

BRAZIL FOCUS



Brazil's two commercial nuclear reactors—Angra-1 and -2—are operated by state-controlled company Eletronuclear at the Central Nuclear Almirante Alvaro Alberto (CNAAA) site and provided the country with a stable 13.7 TWh or 2.5 percent of its electricity in 2022.[73] According to Eletronuclear, Angra-1 achieved the highest monthly electricity output of its operational history in January 2023.[74]

After being suspended in 2015, construction of a third reactor at CNAAA resumed in November 2022. The works were interrupted again in April 2023 due to a dispute with local government, causing a costly delay and threatening the projects viability. The quarrel was seemingly settled over the summer, but a clear path forward is not yet guaranteed, as a financing model and an Engineering, Procurement and Construction (EPC) contract are yet to be approved. The Ministry of Energy had previously indicated that a decision on the future of Angra-3 is expected by the end of the year. Various estimates of the remaining investment requirements are all around BRL20 billion (~US$4 billion), and the latest disclosed commissioning target is 2029.

Brazil is expanding its uranium enrichment capacities and expects to manufacture the entire fuel supply requirements of its then three reactors by 2037. The deployment of further nuclear capacity has long been on the agenda of successive governments, but no definite newbuild plans have been revealed by the previous or the current administration of President Lula da Silva. Over the years, as Angra-3 sunk in turmoil such ambitions had gradually been relegated further into the future, but lobbying efforts continue.

The first contract for constructing a nuclear power plant, **Angra-1**, was awarded to Westinghouse in 1970. The 609-MW PWR eventually went critical in 1981 and is licensed to operate until December 2024. In late 2019, Eletronuclear formally applied for a 20-year lifetime

72 - Ibidem.

73 - Data from IAEA-PRIS. According to Government Data, Brazil produced 14.6 TWh from nuclear in 2022, representing 2.15 percent of the country's total electricity generation, compared to 14.7 TWh and 2.24 percent in 2021; see EPE, "Anuário Estatístico de Energia Elétrica 2023—Ano base 2022", Empresa de Pesquisa Energética/Energy Research Office, Ministry of Mines and Energy, Federal Government of Brazil, May 2023 (in Portuguese), see https://dashboard.epe.gov.br/apps/anuario-livro/, accessed 12 October 2023.

74 - Eletronuclear, "Notas explicativas às demonstrações financeiras intermediárias condensadas do período findo em 31 de março de 2023", as of 31 March 2023 (in Portuguese), see https://www.eletronuclear.gov.br/Quem-Somos/Governanca/Documents/Demonstra%C3%A7%C3%B5es%20Financeiras%20Trimestrais/2023/NE%20MAR2023%20ELETRONUCLEAR.pdf, accessed 9 July 2023.

extension with the regulator (CNEN),[75] and in October 2020, Westinghouse signed a contract to conduct engineering analyses critical to safety, reliability, and long-term operation as part of the program to extend the working life of Angra-1 until 2044.[76] As of September 2020, the process was expected to cost BRL1.2 billion (US$$_{2020}$230 million).[77] In September 2022, Eletronuclear indicated it received the first share of a US$22.3-million loan guaranteed by U.S. Export-Import Bank (EXIM), with a further long-term loan of US$430 million under negotiation.[78] The remaining share of the US$22 million-loan was released in December 2022.[79]

A Pre-"Safety Aspects of Long Term Operation (SALTO)" follow-up mission led in June 2022 by the IAEA, reviewed twenty-one issues that had been identified in 2018 during a previous pre-SALTO mission, and assessed that eleven of these issues were "resolved", eight were subject to "satisfactory progress" and two had seen "insufficient progress".[80] Overall, the experts concluded that preparation work was progressing "in a timely manner". A full scope SALTO mission was expected to take place in 2023,[81] but is now scheduled for early June 2024[82]. In December 2023, Eletronuclear is expected to submit its third Periodic Safety Reassessment (Reavaliação Periódica de Segurança – RPS) to the safety authority.[83]

Angra-2 is a large German-designed PWR with a capacity of 1275 MW that was connected to the grid in July 2000, 24 years after construction initially started. A 30-year license set to expire in 2041 was issued in 2011 but Eletronuclear has announced in the past that it will likely request a 20-year extension.[84] The company indicated in 2022 that studies were already

75 - CNEN, "Eletronuclear solicita à CNEN extensão de vida útil de Angra 1", Comissão Nacional de Energia Nuclear/Federal Commission on Nuclear Energy (in Portuguese), 7 November 2019, Updated 4 November 2022, see https://www.gov.br/cnen/pt-br/assunto/ultimas-noticias/eletronuclear-solicita-a-cnen-extensao-de-vida-util-de-angra-1, accessed 15 July 2023.

76 - Westinghouse, "Westinghouse signs Engineering Contract to extend the life of Angra 1", 5 October 2020, see https://info.westinghousenuclear.com/news/westinghouse-signs-engineering-contract-to-extend-the-life-of-angra-1, accessed 13 June 2022.

77 - Judith Perera, "Nuclear development in Brazil", *Nuclear Engineering International*, 16 September 2020, see https://www.neimagazine.com/features/featurenuclear-development-in-brazil-8137143/, accessed 17 June 2022.

78 - Eletronuclear, "Eletronuclear recebe financiamento externo para estender vida útil de Angra 1", Press Release (in Portuguese), 15 September 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-recebe-financiamento-externo-para-estender-vida-%C3%BAtil-de-Angra-1.aspx; and Eletronuclear, "Relatório Anual 2022", July 2023 (in Portuguese), see https://www.eletronuclear.gov.br/Quem-Somos/Governanca/Documents/Relat%c3%b3rios%20e%20Balan%c3%a7os/Relat%c3%b3rio%20Anual%202022%20-%20Final.pdf; accessed 25 August 2023.

79 - ENBPar, "Demonstrações Financeiras individuais e consolidadas em 31 de dezembro de 2022", Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A., Ministry of Mines and Energy, Government of Brazil, 14 April 2023 (in Portuguese), see https://www.gov.br/mme/pt-br/assuntos/orgaos-vinculados/enbpar/demonstracoes-financeiras-2/demonstracoes-financeiras-em-31-12-2022-enbpar-em-pdf.pdf/view, accessed 11 October 2023.

80 - IAEA, "Pre-SALTO Mission Follow-Up to Angra 1—Executive Summary", International Atomic Energy Agency, 7–10 June 2022, see https://www.iaea.org/sites/default/files/documents/review-missions/35_angra_pre-salto_fu_executive_summary.pdf, accessed 9 July 2023.

81 - IAEA, "IAEA Concludes Long Term Operational Safety Review at Brazil's Angra Nuclear Power Plant", Press Release 107/2022, International Atomic Energy Agency, 10 June 2022, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-brazils-angra-nuclear-power-plant-0, accessed 15 June 2022.

82 - IAEA, "Peer Review and Advisory Services Calendar—Safety Aspects of Long Term Operation (SALTO)", as of 9 July 2023, see https://www.iaea.org/services/review-missions/calendar?type=3169&year%5Bvalue%5D%5Byear%5D=&location=All&status=All, accessed 9 July 2023.

83 - Eletronuclear, "Eletronuclear recebe financiamento externo para estender vida útil de Angra 1", Press Release (in Portuguese), 15 September 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-recebe-financiamento-externo-para-estender-vida-%C3%BAtil-de-Angra-1.aspx, accessed 15 July 2023.

84 - Eletronuclear, "Angra Nuclear Power Station—Initiatives for Long Term Operation", Eletrobras, as presented at "International Nuclear Atlantic Conference", 24–29 November 2013, see http://www.aben.com.br/Arquivos/205/205.pdf, accessed 25 June 2022.

underway to outline a program for the management of "aging of systems, structures and components at the plant, along the same lines as Angra 1."[85]

As reported in WNISR2022, after years of uncertainty, successive setbacks and controversy, in 2022, the Bolsonaro Government finalized the privatization of Eletrobras, the biggest power company in Brazil and, until then, parent entity of Eletronuclear. Requirements for the privatization to succeed included some major restructuring designed to maintain nuclear activities under state control.[86] Hence, a new state agency taking over Eletrobras' activities "that cannot be privatized"—Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A. (ENBpar)—was created by presidential decree on 10 September 2021,[87] and announced to be "active" by the responsible Ministry of Mines and Energy, on 4 January 2022.[88] In June 2022, corporate control over Eletronuclear was transferred to ENBPar, through capital injection of BRL3.5 billion (US$$_{2022}$677 million).[89]

Further institutional changes of recent years include the creation of a new agency to improve the independence of the nuclear regulator. A decree signed by then President Jair Bolsonaro in May 2021 provided for a new regulatory framework and the creation of ANSN (Autoridade Nacional de Segurança Nuclear) which has been reassigned CNEN's (Comissão Nacional de Energia Nuclear) responsibilities to monitor, regulate and inspect nuclear activities and facilities. CNEN will remain in charge of planning, overall policy, and advocacy for nuclear energy.[90] The new allocation and organization was signed into law in October 2021,[91] the statutory structure and organization were approved by decree in July 2022,[92] but, as of July 2023, ANSN has "not yet started to function" as no "Director-President" has yet been appointed. Consequently, in July 2023, the Joint Budget Committee and Parliament approved an Executive Bill, aimed at opening a special credit line of BRL22.9 million (US$4.7 million)

85 - Eletronuclear, "Eletronuclear recebe financiamento externo para estender vida útil de Angra 1", Press Release, 15 September 2022, op. cit.

86 - *CE Noticias Financieras*, "The Federal Audit Court approves privatization, learn what the next steps will be", 18 May 2022.

87 - Federal Government of Brazil, "Decreto N° 10.791, de 10 de Setembro de 2021– Cria a Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A.", *Diário Oficial da União*, Edition 173 (in Portuguese), 13 September 2021, see https://www.in.gov.br/en/web/dou/-/decreto-n-10.791-de-10-de-setembro-de-2021-344145312; and Ministry of Mines and Energy, "Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A. é ativada", Federal Government of Brazil, Press Release (in Portuguese), 4 January 2022, see https://www.gov.br/mme/pt-br/assuntos/noticias/empresa-brasileira-de-participacoes-em-energia-nuclear-e-binacional-s-a-e-ativada; both accessed 16 June 2022.

88 - Ministry of Mines and Energy, "Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A. é ativada", Federal Government of Brazil, Press Release (in Portuguese), 4 January 2022, op. cit.

89 - ENBPar, "Demonstrações Financeiras individuais e consolidadas em 31 de dezembro de 2022", April 2023, op. cit.

90 - Vladimir Pekic, "Brazil approves creation of nuclear regulator separate from CNEN", *Nucleonics Week*, S&P Global, No 62, Issue 20, 20 May 2021; and Government of Brazil, "Sancionada a lei que cria a da Autoridade Nacional de Segurança Nuclear", Press Release (in Portuguese), 18 October 2021, see https://www.gov.br/casacivil/pt-br/assuntos/noticias/2021/outubro/sancionada-a-lei-que-cria-a-da-autoridade-nacional-de-seguranca-nuclear, accessed 17 June 2022.

91 - *Diário Oficial da União*, "Lei No°14.2022, de 15 de Outubro de 2021—Cria a Autoridade Nacional de Segurança Nuclear (ANSN)", enacted 15 October 2021, promulgated 18 October 2021 (in Portuguese), see https://www.in.gov.br/en/web/dou/-/lei-n-14.222-de-15-de-outubro-de-2021-352709951, accessed 10 July 2023.

92 - Federal Government of Brazil, "Decreto aprova a estrutura regimental e quadro de cargos e funções da Autoridade Nacional de Segurança Nuclear (ANSN)", 22 July 2022 (in Portuguese), see https://www.gov.br/secretariageral/pt-br/noticias/2022/julho/decreto-aprova-a-estrutura-regimental-e-quadro-de-cargos-e-funcoes-da-autoridade-nacional-de-seguranca-nuclear-ansn, accessed 14 July 2023.

in the 2023 Budget to provide CNEN with the resources considered necessary to carry out ANSN's duties.[93]

The Angra-3 Saga

Preparatory work for the construction of Angra-3—a 1405-MW PWR designed by Siemens/KWU—started in 1984. It is unclear how much progress was made before a lengthy interruption starting in 1986. In May 2010, Brazil's Nuclear Energy Commission issued a construction license, and the IAEA in its Power Reactor Information System (PRIS) recorded that construction (re)started on 1 June 2010.

In early 2011, the Brazilian National Development Bank (BNDES) approved a BRL6.1 billion (US$$_{2011}$3.65 billion) loan for work on the project and in November 2013, Eletronuclear signed a €1.25 billion (US$$_{2013}$1.7 billion) contract with French builder AREVA for the completion of the plant.[94]

However, a corruption probe led to waves of arrests among plant management, contractors, politicians, heads of state, and senior Eletronuclear executives between 2015 and 2020, and derailed the project altogether (see earlier WNISR editions). In 2015, construction was halted, by 2017 funding had collapsed and the contracts for the construction work were declared void.[95] In August 2017, an audit by the Federal Court of Accounts (TCU) of Eletronuclear studies which evaluated the necessary investment to resume works at BRL17 billion (US$$_{2017}$5.3 billion), noted that "... the increase will have a significant impact on the sale price of the energy to be produced and, consequently, on the viability of the enterprise."[96]

In September 2018, TCU lifted its recommendation to suspend the program due to irregularities[97], and shortly after, the reference value for the price of power from Angra-3 was more than doubled compared to the 2016-value. However, no partner was found to invest in the endeavor, so that in June 2020, the Bolsonaro Government approved plans for carrying out the project, "with or without a partner joining Eletronuclear." That was despite the ongoing corruption investigation, and Eletronuclear's various statements at the time that an additional BRL14.5–15 billion (US$$_{2020}$2.8–2.9 billion) of investment would be needed to complete the

93 - Sílvia Mugnatto, "Projeto abre crédito especial para a Comissão Nacional de Energia Nuclear", Agência Câmara de Notícias, Chamber of Deputies, National Congress of Brazil, 11 July 2023 (in Portuguese), see https://www.camara.leg.br/noticias/979074-projeto-abre-credito-especial-para-a-comissao-nacional-de-energia-nuclear/; and National Congress, "Projeto de Lei do Congresso Nacional nº 13, de 2023", Updated 13 July 2023 (in Portuguese), see https://www.congressonacional.leg.br/materias/pesquisa/-/materia/158694#tramitacoes, accessed 14 July 2023.

94 - *WNN*, "Areva contracted to complete Angra 3", *World Nuclear News*, 8 November 2013, see http://www.world-nuclear-news.org/C-Areva-contracted-to-complete-Angra-3-081134.html, accessed 7 May 2021.

95 - *NEI Magazine*, "Contracts for work at Brazil's Angra 3 declared void", *Nuclear Engineering International*, 6 February 2017, see https://www.neimagazine.com/news/newscontracts-for-work-at-brazils-angra-3-declared-void-5732236, accessed 15 June 2022.

96 - TCU, "Conclusão de Angra 3 pode custar R$ 25 bilhões", Tribunal de Contas da União/Federal Court of Accounts, Press Release (in Portuguese), 29 August 2017, see https://portal.tcu.gov.br/imprensa/noticias/conclusao-de-angra-3-pode-custar-r-25-bilhoes.htm, accessed 15 July 2023.

97 - TCU, "TCU retira a recomendação de paralisação da usina nuclear de Angra 3", Tribunal de Contas da União/Federal Court of Accounts (in Portuguese), 18 September 2018, see https://portal.tcu.gov.br/imprensa/noticias/tcu-retira-a-recomendacao-de-paralisacao-da-usina-nuclear-de-angra-3.htm, accessed 12 July 2023.

unit.[98] Altogether, at that stage, the unit was said to be 62.8 percent complete, while 80 percent of the equipment was reportedly bought and stored, costing about BRL 25 million (US$4.6–4.8 million) per year in "upkeep and insurance".[99]

In March 2021, Eletrobras approved a "Critical Path Acceleration Plan" to complete Angra-3 by 2023 and reach commercial operation by the end of 2026.[100] At that time, Leonardo Mendes Cabral, director of privatizations at BNDES, said he expected a financing arrangement to be ready by the end of 2022. The Brazilian Government and Eletrobras had hired BNDES to develop the project, with an estimated additional cost of US$3–4 billion.[101] In turn, BNDES released a statement in June 2021 indicating that they had hired Angra Eurobras NES—a consortium composed of Belgium's Tractebel Engineering SA, Spanish engineering firm Empresarios Agrupados Internacional SA, and led by Tractebel Engineering Ltd. (a subsidiary of French energy company Engie)—to structure the project going forward. This includes identifying the remaining work needed and the means to contract construction companies, providing investment estimates, and accordingly outline a schedule to complete construction.[102]

In October 2021, ahead of the privatization of Eletrobras, the guidelines for pricing of Angra-3 were approved, clarifying that prices of electricity from Angra-3 would be based on BNDES calculations, taking into account "the economic and financial viability of the project" and "its financeability under market conditions".[103]

Meanwhile, in February 2021, Eletronuclear had launched a tender with the intention to hire a contractor in the second half of 2022 for civil works and electromechanical assembly with the expectation that the unit—which was now said to be 65 percent complete—would enter commercial operation in November 2026.[104] In July 2021, Eletronuclear announced that a consortium, made up of Ferreira Guedes, Matricial and ADtranz, had won the tender with a

98 - Marcela Ayres and Anthony Boadle, "UPDATE 1-Brazil government approves plan to complete third nuclear plant", *Reuters*, 11 June 2020, see https://www.reuters.com/article/brazil-eletrobras-nuclear-idLTAL1N2DN367; and Eletronuclear, "Annual Report 2019, Eletrobras, 14 July 2020, p. 69, see https://eletrobras.com/en/SobreaEletrobras/Annual-Report-2019.pdf; also Judith Perera, "Nuclear development in Brazil", *NEI Magazine*, 16 September 2020, see https://www.neimagazine.com/features/featurenuclear-development-in-brazil-8137143/; all accessed 24 June 2022.

99 - TCU, "Parceria com a iniciativa privada pode ser o caminho para retomar Angra 3", Press Release (in Portuguese), Tribunal de Contas da União/Federal Court of Accounts, 7 February 2020, see https://portal.tcu.gov.br/imprensa/noticias/parceria-com-a-iniciativa-privada-pode-ser-o-caminho-para-retomar-angra-3.htm; and *NEI Magazine*, "Brazil to resume work on Angra 3", 3 March 2021, see https://www.neimagazine.com/news/newsbrazil-to-resume-work-on-angra-3-8564296, accessed 15 June 2022.

100 - *NEI Magazine*, "Brazil to resume work on Angra 3", 3 March 2021, op. cit.

101 - *WNN*, "Brazil to complete Angra 3 finance package in 18 months, says BNDES director", *World Nuclear News*, 22 March 2021, see https://www.world-nuclear-news.org/Articles/Brazil-to-complete-Angra-3-finance-package-in-18-m?feed=feed, accessed 22 March 2021.

102 - Vladimir Pekic, "Brazil's BNDES bank hires consortium to shape Angra-3 project", *Nucleonics Week*, Platts, 1 July 2021.

103 - Ministry of Mines and Energy, "Resolução nº 23— Estabelece diretrizes para a definição do preço da energia da Usina Termelétrica Nuclear Angra 3.N°61, de 20 de outubro de 2021. Resolução n°23, de 20 de outubro de 2021, do Conselho Nacional de Política Energética – CNPE", Diário Oficial da União, approved 21 October 2021, 22 October 2021, see https://www.gov.br/mme/pt-br/assuntos/conselhos-e-comites/cnpe/resolucoes-do-cnpe/resolucoes-2021/ResoluesCNPE23_2021.pdf, accessed 3 November 2023.

104 - *BNAmericas*, "Brazil launches tender to resume Angra 3 nuclear plant works", 26 February 2021, see https://www.bnamericas.com/en/news/brazil-launches-tender-to-resume-angra-3-nuclear-plant-works, accessed 22 March 2021; and *NEI Magazine*, "Brazil to resume work on Angra 3", 3 March 2021, op. cit.

winning bid of BRL292 million (US$$_{2021}$54.1 million).[105] In February 2022, a contract was signed with the consortium.[106]

An Angra Eurobras NES-presentation dated May 2022 indicated that on-site construction was planned to resume in the third quarter 2022. The document enclosed a provisional schedule which projected commissioning of the unit in December 2026 and commercial operation in February 2028.[107] At the time, an additional BRL19.4 billion (US$$_{2022}$3.8 billion) was said to be needed to complete the project.[108]

In June 2022, the privatization of Eletrobras occurred, bringing construction of Angra-3 one step closer to resumption, as it was said to be crucial to the completion of the project.[109]

In September 2022, Angra-3's environmental license was renewed for six years by the Brazilian Institute for Environment and Renewable Natural Resources (Ibama).[110] And finally, on 11 November 2022, Eletronuclear announced the "resumption of concrete pouring", marking the official restart of construction.[111]

A few days later, Tractebel announced in more cautious terms that Angra Eurobras NES had finalized "the first stage of the project that will enable to resume the construction". The consortium delivered an "Engineering, Procurement and Construction [EPC] Contract Specification Report" with the promise that it will "enable BNDES to elaborate the modeling and will provide reliable data for the economic and financial assessment, the fund-raising process, and for the elaboration of the final EPC contract. It is crucial as it will mitigate the project's risks."[112] Modelling by BNDES would then have to gain approval from Eletronuclear and be reviewed by the Ministry of Mining and Energy and TCU, before a final EPC agreement can be contracted.

As of December 2022, the Angra-3 project—with admirable precision—was said to be 66.97 percent complete with an expected operation date of July 2028.[113] However, on 19 April 2023, the City Government of Angra dos Reis ordered the halt of work on the grounds that the project as implemented differed from the initially approved plans. The city indicated

105 - *NEI Magazine*, "Consortium chosen for preliminary work to complete Angra 3", *Nuclear Engineering International*, 29 July 2021, see https://www.neimagazine.com/news/newsconsortium-chosen-for-preliminary-work-to-complete-angra-3-8945927, accessed 16 June 2022.

106 - *WNN*, "Contract signed allowing resumption of Angra 3 works", *World Nuclear News*, 10 February 2022, see https://www.world-nuclear-news.org/Articles/Contract-signed-to-allow-resumption-of-Angra-3-wor, accessed 17 June 2022.

107 - Angra Eurobras NES, "Market Sounding", May 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Documents/2%20-%20Apresenta%C3%A7%C3%A3o%20AEN%20Final.pdf, accessed 15 June 2022.

108 - *CE Noticias Financieras*, "Angra 3 nuclear power plant needs R$19.4 billion to be ready", 17 May 2022.

109 - *bnamericas*, "Failure of Eletrobras privatization could make Angra 3 unviable – BNDES", *Business News Americas*, 7 April 2022.

110 - *NEI Magazine*, "Installation licence renewed for Brazil's Angra 3", *Nuclear Engineering International*, 1 September 2022, see https://www.neimagazine.com/news/newsinstallation-licence-renewed-for-brazils-angra-3-9969340, accessed 1 July 2023.

111 - Eletronuclear, "Reinício da concretagem marca retomada das obras de Angra 3", Press Release (in Portuguese), 11 November 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Rein%C3%ADcio-da-concretagem-marca-retomada-das-obras-de-Angra-3.aspx, accessed 1 July 2023.

112 - Tractebel, "Restart of nuclear reactor's construction in Brazil moves forward", Press Release, Engie, 16 November 2022, see https://tractebel-engie.com/en/news/2022/restart-of-nuclear-reactor-s-construction-in-brazil-moves-forward; and *NEI Magazine*, "Tractebel supports construction of Brazil's Angra 3", *Nuclear Engineering International*, 22 November 2022, see https://www.neimagazine.com/news/newstractebel-supports-construction-of-brazils-angra-3-10376578, accessed 1 July 2023.

113 - Eletrobras, "Form 20-F—Annual Report Pursuant to Section 13 or 15(D) of the Securities Exchange Act of 1934 for the Fiscal Year Ended December 31, 2022", Centrais Elétricas Brasileiras S.A., filed with the U.S. Securities and Exchange Commission, 20 April 2023, see https://static.poder360.com.br/2023/04/20-F-2022.pdf, accessed 12 July 2023.

that they would grant a new construction permit upon review and approval of the changes, and once Eletronuclear honors its 2009-commitment to a socio-environmental compensation equivalent to BRL264 million (US$54.5 million) in 2023-value.[114]

It appears noteworthy that the dispute builds on recent tensions between the company and local government. In March 2023, a Public Civil Action was filed against Eletronuclear over an incident that occurred on 16 September 2022 during Angra-1's refueling outage which the operator failed to disclose to regulatory agencies. According to available information, on 29 September 2022, Ibama was alerted of a contaminated water discharge that led to a joint inspection and continued monitoring with CNEN, which concluded that the measured levels "did not pose any risk to the population and the environment." In February 2023, Ibama fined Eletronuclear over BRL2 million (~US$392,000) for illegal disposal of contaminated water, and BRL101,000 (~US$19,800) for neglecting to promptly alert the regulator of the event. The following month, the Public Prosecutor filed a public civil action against Eletronuclear,[115] which prompted a police search on-site in May 2023 and debates and hearings in Parliament.[116]

Eletronuclear firmly rejected the allegations of non-compliance with the 2009-agreement and tried to lift the suspension[117] while establishing legal action as an option should the administrative proceedings and dialogue attempts fail.[118] As of early June 2023, the dialogue on compensation funding seemed to reach some progress[119], and a month later, Eletronuclear indicated it was reviewing projects submitted by the municipality to assess if these were eligible to receive parts of the funds earmarked towards socio-environmental compensation.[120] A few days later, it was announced that an agreement had been outlined under which Eletronuclear would distribute more than BRL300 million (~US$62 million) in five settlements to three municipalities neighboring CNAAA until 2027, including the BRL264 million for Angra dos Reis.[121] Early in the negotiations, in May 2023, Eletronuclear CEO Eduardo Grivot had indicated "I signed the commitment of R$264 million, which was presented by the city council, but I won't have the money to pay it all." The new accord was to be signed by early August 2023;

114 - Prefeitura Municipal de Angra dos Reis, "Prefeitura embarga obras da usina nuclear Angra 3", Press Release (in Portuguese), 20 April 2023, see https://www.angra.rj.gov.br/noticia.asp?vid_noticia=65607&indexsigla=imp, accessed 12 July 2023.

115 - Cedê Silva, "Brazilian nuclear power company hid radioactive leak", *The Brazilian Report*, 24 March 2023, see https://brazilian.report/environment/2023/03/24/nuclear-power-radioactive-leak/, accessed 30 June 2023; and *BNN*, "Eletronuclear Fined for Accident at Angra 1 Nuclear Power Plant in Brazil", March 2023, see https://bnn.network/world/brazil/eletronuclear-fined-for-accident-at-angra-1-nuclear-power-plant-in-brazil/, accessed 13 July 2023.

116 - Câmara dos Deputados, "Commisão de Minas e Energia debate vazamento radioativo em Angra dos Reis", Chamber of Deputies, National Congress of Brazil, 16 May 2023, see https://www.camara.leg.br/noticias/960596-comissao-de-minas-e-energia-debate-vazamento-radioativo-em-angra-dos-reis/, accessed 1 July 2023.

117 - Eletronuclear, "Eletronuclear contesta autuação das obras de Angra 3 pela prefeitura de Angra dos Reis", Press Release (in Portuguese), 8 May 2023, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-contesta-autua%C3%A7%C3%A3o-das-obras-de-Angra-3-pela-prefeitura-de-Angra-dos-Reis.aspx; and Eletronuclear, "Eletronuclear busca reverter embargo às obras de Angra 3", Press Release (in Portuguese), 20 May 2023, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-busca-reverter-embargo-%C3%A0s-obras-de-Angra-3.aspx; both accessed 16 July 2023.

118 - Eletronuclear, "Eletronuclear esclarece dúvidas sobre convênios com prefeituras de Angra dos Reis e Paraty", Press Release (in Portuguese), 20 May 2023, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-esclarece-d%C3%BAvidas-sobre-conv%C3%AAnios-com-prefeituras-de-Angra-dos-Reis-e-Paraty.aspx, accessed 16 July 2023.

119 - Prefeitura Municipal de Angra dos Reis, "Prefeitura e Eletronuclear buscam entendimento sobre Angra 3", 8 June 2023.

120 - Eletronuclear, "Eletronuclear analisa projetos enviados pela prefeitura de Angra dos Reis", Press Release (in Portuguese), 12 July 2023, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-analisa-projetos-enviados-pela-prefeitura-de-Angra-dos-Reis.aspx, accessed 16 July 2023.

121 - Prefeitura Municipal de Angra dos Reis, "Eletronuclear se compromete a pagar dívida com Angra", Press Release (in Portuguese), 17 July 2023, see https://www.angra.rj.gov.br/noticia.asp?vid_noticia=65965&IndexSigla=imp, accessed 14 October 2023.

however, no precise information was disclosed concerning the reissuance of construction permits.[122]

The delays come at great cost that could "threaten the financial viability" of the project, as it could force Eletronuclear to repay debts and loan obligation of BRL 6.2 billion (US$1.25 billion) prior to commissioning.[123] This could also adversely impact stakeholder Eletrobras that states in financial documents filed in April 2023 that "We may incur substantial financial liabilities as well as unexpected expenses until we complete the construction of the Angra 3 nuclear power plant."[124]

Governmental support remains crucial. President Luiz Inácio Lula da Silva backed the "relaunch" of Angra-3 during his previous presidency (2003–2010),[125] so the support of his administration upon taking office in January 2023 did not only appear guaranteed but was also reaffirmed on several instances. Notably during a parliamentary commission hearing held in early May 2023. On that occasion, Secretary of Electricity Gentil Nogueira de Sá Junior also disclosed that commissioning would not occur before 2029 and that abandoning the project would cost about BRL13.6 billion (US$2.7 billion), while the funding options of the remaining investment required—amounting to BRL20 billion (US$4 billion)—were still under BNDES review. According to the Secretary of Electricity's presentation before Parliament, the revised cost of the project increased to BRL27.8 billion (US$5.5 billion).[126]

ENBPar had earlier hinted towards even higher costs in its Annual Report for 2022, when it referred to an "ongoing due diligence report"—seemingly quoting from Angra Eurobras NES' review—which estimates the remaining investment needed at BRL21 billion (US$4.3 billion).[127]

Eletronuclear's Annual Report 2022 noted that a bidding notice for EPC was expected by the end of 2023, and contract signature in the first trimester of 2024.[128] In any way, as then-president of Eletronuclear Leonam Guimaraes summarized in May 2020, "It is much easier to attract partners with a project that is under way than with one that is paralyzed."[129]

122 - Prefeitura Municipal de Angra dos Reis, "Eletronuclear diz não ter dinheiro para pagar Angra", Press Release (in Portuguese), 16 May 2023, see https://angra.rj.gov.br/noticia.asp?vid_noticia=65705, accessed 1 June 2023; and Prefeitura Municipal de Angra dos Reis, "Eletronuclear se compromete a pagar dívida com Angra", Press Release, 17 July 2023, op. cit.

In September 2023 it was reported that a Civil Court had reversed a decision that permitted work to resume at Angra 3; see *NEI Magazine*, "Eletronuclear to appeal court decision halting work at Angra 3", 19 September 2023, see https://www.neimagazine.com/news/newseletronuclear-to-appeal-court-decision-halting-work-at-angra-3-11157755, accessed 16 October 2023.

123 - Jessica Sondgeroth, "Newbuild: Angra-3 Developers Face New Headwinds", *Energy Intelligence*, 12 May 2023, see https://www.energyintel.com/00000188-0b92-d836-a3af-1f9765a40000, accessed 9 July 2023.

124 - Eletrobras, "Form 20-F—Annual Report Pursuant to Section 13 or 15(D) of the Securities Exchange Act of 1934 for the Fiscal Year Ended December 31, 2022", April 2023, op.cit.

125 - *WNN*, "Brazil backs nuclear energy", *World Nuclear News*, 11 July 2007, see https://www.world-nuclear-news.org/Articles/Brazil-backs-nuclear-energy, accessed 30 June 2023.

126 - Alexa Salomão, "Conclusão da usina nuclear de Angra 3 é prioridade nos planos do governo Lula", *Folha de S.Paulo* (in Portuguese), 4 May 2023; and *Reuters*, "Governo projeta mais R$ 20 bi para terminar Angra 3 e começar operação até 2029", as published by *CNN Brasil* (in Portuguese), 3 May 2023, see https://www.cnnbrasil.com.br/economia/governo-projeta-mais-r-20-bi-para-terminar-angra-3-e-comecar-operacao-ate-2029/, accessed 10 July 2023.

127 - ENBPar, "Demonstrações Financeiras individuais e consolidadas em 31 de dezembro de 2022", 14 April 2023, op. cit.

128 - Eletronuclear, "Relatório Annual 2022", 2023, see https://www.eletronuclear.gov.br/Quem-Somos/Governanca/Documents/Relat%C3%B3rios%20e%20Balan%C3%A7os/Relat%C3%B3rio%20Anual%202022%20-%20Final.pdf, accessed 16 October 2023.

129 - Anthony Boadle, "COVID-19 to delay Brazil nuclear plant -Eletronuclear", *Reuters*, 22 May 2020, see https://www.reuters.com/article/nuclear-brazil-idUSL1N2D319L, accessed 10 July 2023.

In late June 2023, Energy Minister Alexandre Silveira de Oliveira had stated that the decision on whether to restart this "big challenge" was still pending, with a final ruling expected by year's end.[130]

The matter has become increasingly sensitive to the administration, whose indecisiveness is reflected in its new "Growth Acceleration Program" or PAC (Programa de Aceleração do Crescimento) released in August 2023.[131] The nationwide program maps BRL1.7 trillion (US$360 billion) of public and private investment towards a wide range of sectors, such as urbanization, health, education, or culture, until 2026. Of the BRL75.7 billion (US$16 billion) allocated to power generation, just BRL1.9 billion (US$402 million) in state funds are allocated to new nuclear capacity. However, the plan only lists the modernization of Angra-1 as explicit recipient. Angra-3 is not considered an ongoing project and is solely referenced regarding its "technical, economic and socio-environmental feasibility study".[132] Reports indicate that it could still be included in an updated version of PAC, once financing and contracting models are approved.[133] On the matter, Minister of Energy, Silveira was quoted as saying "We need to have economic security that the energy that Angra 3 will supply… will also be economical for the consumer, because it is the consumer who pays the energy bill."[134]

So far, broader political support for the project and further newbuild seems relatively strong. A joint parliamentary group—composed of 217 elected representatives of the Chamber of Deputies and the Senate (of a total of 513 Deputies and 81 Senators)—created earlier in the year to promote new nuclear projects,[135] has been "working to show the government how important, necessary and strategic it is to restart the work on Angra 3 with the utmost urgency" according to its initiator and President, Júlio Lopes (Partido Progressistas).[136]

Expanding Brazil's nuclear capacity beyond Angra-3 has been a clear aspiration of the previous administration for the longer term. In November 2021, at COP26, then Minister of Mines and Energy Bento Costa Lima said the country would add 10 GW of nuclear power over the next

130 - Catarina Demony, "Exclusive: Brazil aims to pass offshore wind, green hydrogen laws by year-end, energy minister says", *Reuters*, 27 June 2023, see https://www.reuters.com/sustainability/climate-energy/brazil-aims-pass-offshore-wind-green-hydrogen-laws-by-year-end-energy-minister-2023-06-27/, accessed 30 June 2023.

131 - Government of Brazil, "Novo PAC vai investir R$ 1,7 trilhão em todos os estados do Brasil", Press Release (in Portuguese), 11 August 2023, see https://www.gov.br/planalto/pt-br/acompanhe-o-planalto/noticias/2023/08/novo-pac-vai-investir-r-1-7-trilhao-em-todos-os-estados-do-brasil, accessed 15 October 2023.

132 - Federal Government of Brazil, "Novo PAC—Transição e Segurança Energética—Geração de energia", August 2023 (in Portuguese), see https://www.gov.br/casacivil/novopac/transicao-e-seguranca-energetica/geracao-de-energia, accessed 16 October 2023.

133 - Gabriela Ruddy, "Governo aguarda BNDES para incluir Angra 3 no PAC", *agência epbr*, 30 August 2023, see https://epbr.com.br/governo-aguarda-bndes-para-incluir-angra-3-no-pac/, accessed 16 October 2023.

134 - *NEI Magazine*, "Angra 3 included in Brazil's growth programme but future remains uncertain", 16 August 2023, see https://www.neimagazine.com/news/newsangra-3-included-in-brazils-growth-programme-but-future-remains-uncertain-11076894, accessed 16 October 2023.

135 - Julio Lopes, "Requerimento N°809/2023—Requer o registro da Frente Parlamentar Mista da Tecnologia e Actividades Nucleares (FPN), nos termos do Ato da Mesa n°69 de 10.11.2005", Câmara dos Deputados/Chamber of Deputies, National Congress of Brazil, 1 February 2023, submitted 21 March 2023 (in Portuguese), see https://www.camara.leg.br/internet/deputado/Frente_Parlamentar/54370-integra.pdf; and Câmara dos Deputados, "Lançamento da Frente Parlamentar Mista da Tecnologia e Atividades Nucleares", Chamber of Deputies, National Congress of Brazil, April 2023 (in Portuguese), see https://www.camara.leg.br/eventos-divulgacao/evento?id=97266; both accessed 1 July 2023.

136 - *Petronotícias*, "Classe Política Reage Contra a Ideia de Abandonar Angra 3 e Diz Que é Inadmissível Não Concluir as Obras da Usina", 27 June 2023 (in Portuguese), see https://petronoticias.com.br/classe-politica-reage-contra-ideia-de-abandonar-angra-3-e-diz-que-e-inadmissivel-nao-concluir-as-obras-da-usina/, accessed 10 July 2023.

30 years,[137] as envisaged by the "National Energy Plan to 2050" or PNE 2050 (Plano Nacional de Energia 2050) and amended by the Government in December 2020.[138]

However, short-term projections remain limited. In January 2022, the Ministry of Mines and Energy published its "Ten-Year Energy Expansion Plan" or PDE 2031 (Plano Decenal de Expansão de Energia 2031), which unveiled a plan to commission a new 1 GW unit by 2031, bringing nuclear power's share in the national electricity production to 4 percent for 33 TWh of generated power.[139] In its final months, the Bolsonaro administration issued the PDE 2032, which projects 1.4 GW of new capacity derived from nuclear over the next decade.[140]

A few known steps were taken in 2022 to further expand nuclear capacity. The Bolsonaro Government released a statement in March 2022 indicating that it has signed a cooperation agreement with the Electric Energy Research Center (Cepel) to identify appropriate sites for new nuclear plants.[141] No locations were named, although in May 2023, the Municipality of Angra dos Reis mentioned in a statement that "the federal government has already announced its intention to build a fourth nuclear power plant in the city."[142] In 2022, interest towards Small Modular Reactors (SMRs) translated into various preliminary governmental and industrial cooperation agreements with Russia and France.[143] That ambition also has a voice in parliament through Julio Lopes who is championing the examination of building an SMR at Angra.[144]

As of July 2023, PEN 2050 and PDE 2032 had not been updated, and it is not entirely clear if and how the incoming Government of President Lula da Silva will revise or implement the current

137 - Rebecca Campbell, "Brazil takes first step towards expanding its nuclear generation capacity", *Engineering News*, 18 January 2022, see https://www.engineeringnews.co.za/print-version/brazil-takes-first-step-towards-expanding-its-nuclear-generation-capacity-2022-01-18, accessed 16 June 2022.

138 - EPE, "PNE 2050 — Plano Nacional de Energia", Empresa de Pesquisa Energética/Energy Research office, Ministério de Minas e Energia/Ministry of Mines and Energy, Federal Government of Brazil, final version approved 16 December 2020, see https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-227/topico-523/05.05 Energia Nuclear.pdf, accessed 16 June 2022.

139 - EPE, "Plano Decenal de Expansão de Energia 2031", Empresa de Pesquisa Energética/Energy Research office, Ministério de Minas e Energia/Ministry of Mines and Energy, Federal Government of Brazil, 2022 (in Portuguese), see https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/Documents/PDE%202031_RevisaoPosCP_rvFinal.pdf, accessed 16 June 2022; and
EPE, "2031 Ten-Year Energy Expansion Plan", Energy Research office, Ministry of Mines and Energy, Federal Government of Brazil, see https://www.epe.gov.br/sites-en/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-245/Relatorio_PDE2031_Cap03_EUS.pdf, accessed 23 October 2023; also Vladimir Pekic, "New nuclear plant to be complete in 2031: Brazilian energy ministry", *Nucleonics Week*, S&P Global, No 63, Issue 5, 3 February 2022.

140 - EPE, "Nota Técnica—Energia e Meio Ambiante – Plano Decenal de Expansão de Energia – PDE 2032", Empresa de Pesquisa Energética/ Energy Research Office, Ministry of Mines and Energy, Federal Government of Brazil, December 2022, see https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-689/topico-639/NT%20Energia%20e%20Meio%20Ambiente%20-%20PDE%202032.pdf, accessed 16 October 2023.

141 - Government of Brazil, "Brazil and the Electric Energy Research Center's agreement to study new sites for nuclear plants", 2 March 2022, see https://www.gov.br/en/government-of-brazil/latest-news/2022/brazil-and-the-electric-energy-research-centers-agreement-to-study-new-sites-for-nuclear-plants, accessed 17 June 2022.

142 - Prefeitura Municipal de Angra dos Reis, "Eletronuclear diz não ter dinheiro para pagar Angra", Press Release (in Portuguese), 16 May 2023, see https://www.angra.rj.gov.br/noticia.asp?vid_noticia=65705&IndexSigla=SGRI, accessed 15 October 2023.

143 - *WNN*, "Russia, Brazil presidents discuss small nuclear plants", *World Nuclear News*, 17 February 2022, see https://www.world-nuclear-news.org/Articles/Russia,-Brazil-presidents-discuss-small-nuclear-pl; and
Eletronuclear, "Eletronuclear e EDF renovam memorando de entendimento", Press Release (in Portuguese), 2 June 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Eletronuclear-e-EDF-renovam-memorando-de-entendimento.aspx; also MME, "ENBPar e Rosatom buscam cooperação para novas fontes de energia verde", Ministério de Minas e Energia/Ministry of Mines and Energy, Federal Government of Brazil, Press Release (in Portuguese), Updated 4 October 2022, see https://www.gov.br/mme/pt-br/assuntos/noticias/enbpar-e-rosatom-buscam-cooperacao-para-novas-fontes-de-energia-verde; all accessed 15 July 2023.

144 - Eletronuclear, "O Rio de Janeiro e o Programa Nuclear Brasileiro – entrevista com o deputado Júlio Lopes", 28 December 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/O-Rio-de-Janeiro-e-o-Programa-Nuclear-Brasileiro-entrevista-com-o-deputado-Julio-Lopes.aspx, accessed 15 July 2023.

targets.[145] It is not clear either, which administration—past or present, or both—has expressed the ambition of a fourth unit at Angra, as disclosed by local officials (see above). Historically, during Lula's second term, his administration intended to build four reactors starting in 2015, and Eletronuclear had the confidence to plan the construction of six reactors adding 8 GW of nuclear capacity by 2030.[146] However, these targets have long slipped away, and while there are clear efforts to keep the option on the table, the overall prospects of nuclear newbuild in Brazil is likely bound to the increasingly uncertain fate of Angra-3.

Expansion of Uranium Enrichment Capacities and Nuclear Fuel Diversification

In November 2022, Indústrias Nucleares do Brasil (INB) inaugurated the tenth cascade of ultracentrifuges for uranium enrichment at its fuel manufacturing facility (Fábrica de Combustível Nuclear – FCN) in Resende, Rio de Janeiro. The expansion of its uranium enrichment capacities deems INB capable of covering 70 percent of the yearly fuel supply necessary to operate Angra-1. Brazil expects to provide the entirety of fuel required by Angra-1 and -2 by 2033, and be completely "self-sufficient" by 2037, though this only entails the needs of the two operating Angra units plus Angra-3, not of further potential future units.[147]

For now, Brazil relies on nuclear fuel imports, and in December 2022, INB and a Rosatom subsidiary signed their first long-term contract for the fuel supply of Angra-1 and -2, from 2023 to 2027.[148]

The Russian nuclear industry remains a regular supplier to its Brazilian counterpart. On 13 March 2023, Rosatom announced that its subsidiary TVEL had won the tender for the supply of more than 100 kg of lithium-7 hydroxide for the reactor cooling system of Unit 1 and 2, indicating that contract signature and shipment was expected to occur before the end of the year.[149] However, Eletronuclear indicated that due to Russia's invasion of Ukraine, it had encountered difficulties in acquiring the product, prompting the company to seek to diversify its supply.[150] A contract was signed in May 2023 with Rosatom's Tenex, during the "Nuclear Trade & Technology Exchange" conference for the supply of natural uranium hexafluoride (UF6), after the Russian corporation won a tender for the supply of 330 tons of UF6 in 2022.[151]

145 - Nick Ferris, "What four years of 'non-existent' climate action has done to Brazil", *Energy Monitor*, 29 September 2022, see https://www.energymonitor.ai/policy/bolsonaro-what-four-years-of-non-existent-climate-action-has-done-to-brazil/, accessed 15 July 2023.

146 - *WNN*, "Brazil to select nuclear site in 2008", *World Nuclear News*, 24 August 2007, see https://www.world-nuclear-news.org/Articles/Brazil-to-select-nuclear-site-in-2008, accessed 15 July 2023.

147 - INB, "INB inaugura cascata de enriquecimento isotópico de urânio e conclui primeira etapa de usina", Indústrias Nucleares do Brasil, Press Release (in Portuguese), 25 November 2022, see https://www.inb.gov.br/pt-br/Detalhe/Conteudo/inb-inaugura-cascata-de-enriquecimento-de-uranio-isotopico-e-conclui-primeira-et/Origem/593; and *NEI Magazine*, "INB completes first stage of uranium enrichment plant", *Nuclear Engineering International*, 29 November 2022, see https://www.neimagazine.com/news/newsinb-completes-first-stage-of-uranium-enrichment-plant-10391917/; both accessed 16 July 2023.

148 - *Interfax*, "Rosatom to supply uranium products to Brazil", 7 December 2022, see https://interfax.com/newsroom/top-stories/85789/, accessed 16 July 2023.

149 - TVEL JSC, "Subsidiary of Rosatom's TVEL Fuel Company will supply lithium-7 for a nuclear power plant in Brazil", Press Release, Rosatom, 13 March 2023, see https://www.rosatom.ru/en/press-centre/news/subsidiary-of-rosatom-s-tvel-fuel-company-will-supply-lithium-7-for-a-nuclear-power-plant-in-brazil/, accessed 16 July 2023.

150 - Eletronuclear, "Relatório Annual 2022", 2023, op. cit.

151 - *NEI Magazine*, "INB signs agreements during nuclear trade conference in Brazil", 9 May 2023, see https://www.neimagazine.com/news/newsinb-signs-agreements-during-nuclear-trade-conference-in-brazil-10830327, accessed 16 October 2023.

Strong Expansion of Renewable Energy Generation

Meanwhile, according to the Energy Institute, the share of fossil fuels in the country's electricity generation mix dropped by close to half in one year, falling from 20 percent in 2021, to 10.1 percent in 2022. Their production decreased by over half for natural gas (from 87 TWh to 42.1 TWh), by half for oil (from 20.2 TWh to 10.1 TWh) and by 30 percent for coal (24.2 to 16.5 TWh). The output from non-hydro renewable sources grew by 10 percent (from 144.8 TWh to 164.5 TWh) and that of hydro by 17.7 percent (from 362.8 TWh to 427.1 TWh), resulting in a contribution of 24.3 percent (154.6 TWh) from non-hydro renewables and a remarkable 87.3 percent (591.6 TWh) of renewables including hydroelectricity. Nuclear generation remained stable at 14.6 TWh in 2022 (compared to 14.7 TWh in 2021), for a 2.2 percent contribution.

The government indicates that 80 percent of the additional power covered by PAC will be low-carbon, of which 79 percent will originate from renewable sources.[152]

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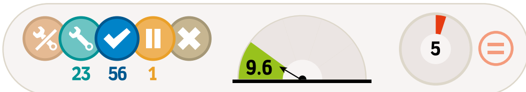


As of mid-2023, China had 56 reactors in operation with a total capacity of around 53 GW. The count of 56 is slightly different from the IAEA's count of 55 in its PRIS database because WNISR records the Shidao Bay as twin High-Temperature Reactor Pebble-bed Modules (HTR-PM) with two reactors of 100 MW each. For unknown reasons, the China Experimental Fast Reactor (CEFR) is no longer mentioned in the PRIS database since May 2023, and has been placed in LTO as of this date in WNISR statistics. With 23 reactors under construction, China continues to be the global leader in hosting nuclear newbuild projects.

Nuclear plants produced 395.4 TWh in 2022, marginally higher (+3.2 percent) than the 383.2 TWh generated in 2021. The electricity generated was 5 percent of the total electricity produced in 2022, the same as in 2021. In comparison, the 2023 "Statistical Review of World Energy" records nuclear power's share of total electricity produced (gross) as 4.7 percent, again the same as 2021.

Since the publication of WNISR2022, only two nuclear reactors have started operating: Fangchenggang-3, a 1000-MW Hualong One, became critical on 27 December 2022, was connected to the grid on 10 January 2023, and was declared as operating commercially on 25 March 2023.[153] The reactor's first pour of concrete was on 24 December 2015, which represents a construction period of 84.5 months.

At the Shidao Bay HTR-PM plant, grid connection of the second of the twin reactors has not been announced. While the production of the plant is not reported, WNISR nevertheless considers both modules to be operating since the end of 2022. According to a report in *World Nuclear News* (*WNN*), the plant "achieved the initial full-power operation of the dual reactors and 'tested the operation control capability' of it in 'two reactors with one machine'

152 - Government of Brazil, "Novo PAC—Transição e Segurança Energética—Geração de energia", August 2023, op. cit.

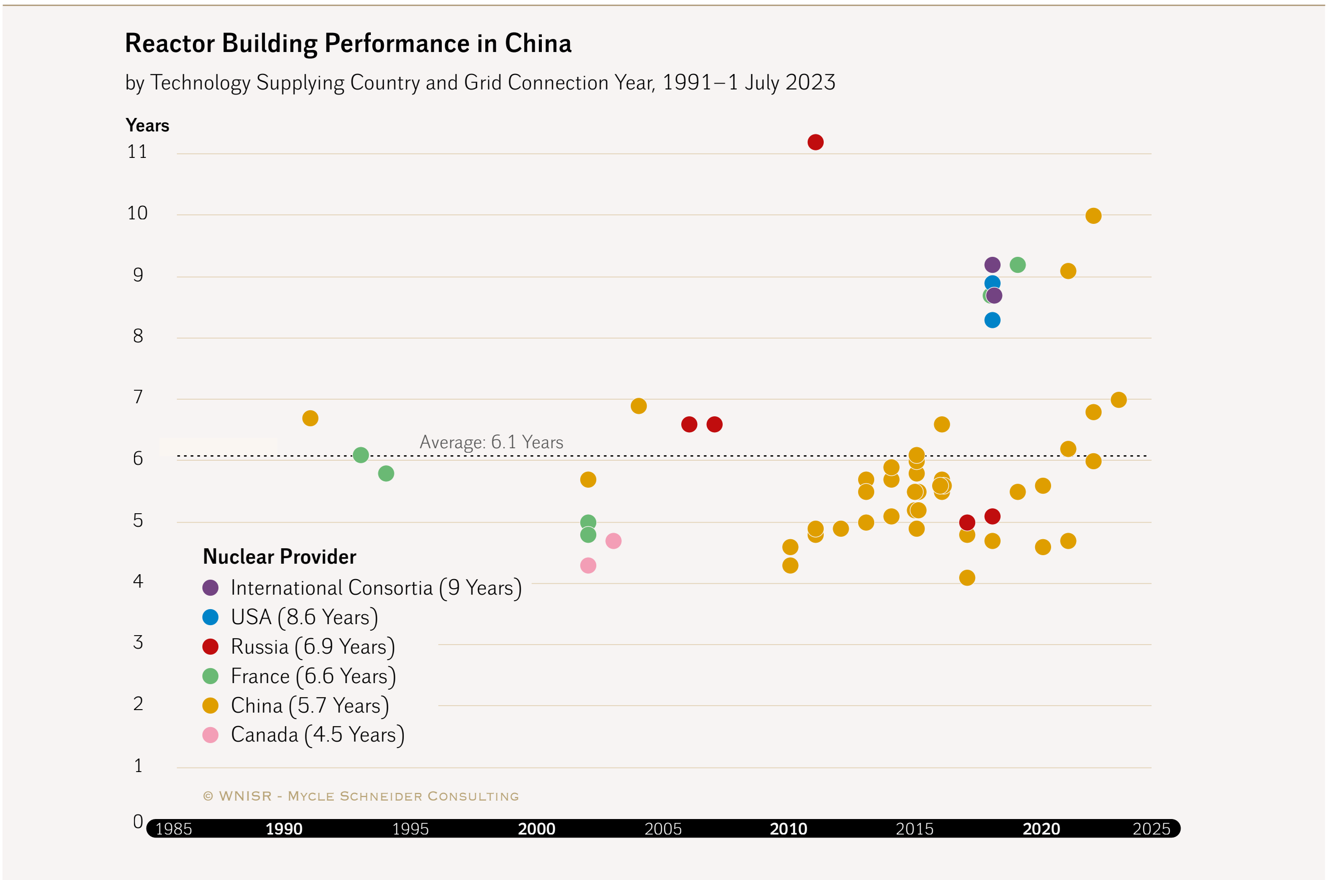
153 - *WNN*, "First CGN Hualong One reactor enters commercial operation", *World Nuclear News*, 27 March 2023, see https://world-nuclear-news.org/Articles/First-CGN-Hualong-One-reactor-enters-commercial-op, accessed 30 July 2023.

mode", which suggests that both reactors were operational, and the "first reactor reached first criticality in September 2021 and the second one that November. The connection of the first of the unit's twin reactors took place in December 2021."[154]

China has imported reactor technologies from Canada, France, Russia, the U.S. and from a U.S.-Japanese consortium (Westinghouse/Mitsubishi Heavy Industries). The first foreign unit, Daya Bay-1 designed by Framatome, started building in July 1987, the latest one, Xudabu-4 a Russian VVER-1200, started construction in May 2022.

It is interesting to assess the construction durations of the 57 units connected to the Chinese grid between 1991 and July 2023. The 41 reactors of Chinese or Sinicized design had an average construction time of 5.7 years with a range from 4.1 to 10 years, while it took on average respectively only 4.5 years for two Canadian CANDUs, but 6.6 years for six French units (4.4-9.2 years), 6.9 years for four Russian reactors (5–11.2 years), 8.6 years for two U.S. AP-1000s, and 9 years for two AP-1000s built by a U.S.-Japanese consortium (see Figure 26).

Figure 26 · Construction Times of Reactors Built in China



Sources: WNISR with IAEA-PRIS, 2023

154 - *WNN*, "China's demonstration HTR-PM reaches full power", *World Nuclear News*, 9 December 2022, see https://www.world-nuclear-news.org/Articles/China-s-demonstration-HTR-PM-reaches-full-power, accessed 9 December 2022.

China has a further 23 reactors under construction, with a combined capacity of around 24.5 GW (see also Annex 3 – Table 29 • "Nuclear Reactors in the World Under Construction"):

- The two CAP1400 reactors, Shidao Bay 2-1 and Shidao Bay 2-2, (since 2019) which are not listed in the IAEA's PRIS database.
- Four units started construction since WNISR2022: Haiyang-3 (7 July 2022), Lufeng-5 (8 September 2022), Sanmen-4 (22 March 2023) and Haiyang-4 (22 April 2023).[155]
- Other light water reactors being built are Fangchenggang-4 (since 2016); Zhangzhou-1, Taipingling-1; Taipingling-2, Sanaocun-1, and Zhangzhou-2 (since 2020); Changjiang-3 and -4, Sanaocun-2, Tianwan-7, and Xudabu-3 (since 2021); Tianwan-8, Xudabu-4 and Sanmen-3 (since 2022).
- The Xiapu two fast reactor units started being built on 29 December 2017 and 27 December 2021 respectively.[156]
- The SMR Changjiang (or Linglong-1) is under construction since 2021.
- The only reactor construction that is currently officially past the deadline for starting is Fangchenggang-4, an HPR-1000 or Hualong One which was originally scheduled to start operating in 2022 and is now scheduled to be connected to the grid in the first half of 2024.[157]

Chinese government authorities have plans for many more. In May 2023, the Ministry of Ecology and Environment "approved in principle" the Environmental Impact Reports for two Hualong One units at the Fangchenggang site and two CAP-1000 units at the new Bailong site, around 30 km away from the Fangchenggang site.[158] These have so far not been approved by the State Council. Plans for the CAP1000 units go back to at least 2015 when a report produced in part by the U.S. Department of Commerce listed them as "nearer-term planned".[159]

China's ambitions include exporting nuclear power plants all over the world. In 2016, the president of China National Nuclear Corporation (CNNC) announced that "China aims to build 30 overseas nuclear power units... by 2030".[160] As described in Annex 1 (see section on Pakistan), China has exported several reactors to that country and is continuing to do so. But so far there has been no other country that has imported a nuclear power plant from China,

155 - David Dalton, "Construction Begins Of Haiyang-3 CAP1000 Nuclear Power Plant", *NucNet*, 18 July 2022, see https://www.nucnet.org/news/construction-begins-of-haiyang-3-cap1000-nuclear-power-plant-7-1-2022; and CGN Power, "The Commencement of Construction of Lufeng Unit 5", 8 September 2022, see http://en.cgnp.com.cn/encgnp/c211222/2022-09/08/ac171a8bcbfa4bca8eacd1717a86e92c/files/22ad3278b9a449beacdc249d8af76b78.pdf; also CNNC, "Construction Starts on Sanmen 4", 23 March 2023, see https://en.cnnc.com.cn/2023-03/23/c_871829.htm; and SNERDI, "海阳核电4号机组顺利实现FCD" ["Haiyang Nuclear Power Unit 4 Successfully Achieves FCD"], Press Release (in Chinese), Shaighai Nuclear Engineering Research & Design Institute Co, LTD., 22 April 2023, see https://www.snerdi.com.cn/newsdetail?id=9277; all accessed 30 July 2023.

156 - *WNN*, "China begins building pilot fast reactor", *World Nuclear News*, 29 December 2017, see http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html, accessed 17 June 2019; and *NEI Magazine*, "China begins construction of second CFR-600 fast reactor", 4 January 2021, see https://www.neimagazine.com/news/newschina-begins-construction-of-second-cfr-600-fast-reactor-8435608, accessed 5 January 2021.

157 - *WNN*, "Nuclear growth revealed in China's new Five-Year Plan", *World Nuclear News*, 23 March 2016, see http://www.world-nuclear-news.org/NP-Nuclear-plans-revealed-in-Chinas-new-Five-Year-Plan-2303166.html, accessed 25 February 2017.

158 - Kim Feng Wong, "China: Guangxi Grabs More Reactor Slots", *Energy Intelligence*, 2 June 2023, see https://www.energyintel.com/00000188-7647-d04b-abbe-f7572e630000, accessed 29 July 2023.

159 - Nicobar Group, "China's Nuclear Industry in 2015 - Moving Forward", Nicobar Group, in cooperation with U.S. Commercial Service, Department of Commerce, 24 April 2015, see https://dokumen.tips/documents/chinas-nuclear-industry-in-2015-build-egcndocumentsweb-chinas.html, accessed 21 August 2023.

160 - Xinhua, "China plans 30 overseas nuclear power units by 2030", 1 March 2016.

possibly because of the United States blacklisting Chinese nuclear firms in 2019, accusing them of helping acquire U.S. technology for military use.[161] Also, in 2019, the U.S. Department of Commerce added China General Nuclear Power Group (CGN) to its "entity list", as a result of which U.S. companies cannot sell "products and services to the firm without written approval".[162]

Therefore, the February 2022 agreement signed by CNNC and Nucleoeléctrica Argentina SA (NA-SA) to build Atucha-3 was seen as an important beginning.[163] But, as NA-SA President Jose Luis Antunez clarified in an interview with *Nuclear Intelligence Weekly* in early 2022, the agreement to execute the project required "precedent conditions" to be met, including CNNC "transferring the technology for fabricating the metallic component of the fuel in Argentina".[164]

Argentina's demand that it be allowed to "manufacture the reactor fuel" is reportedly becoming an obstacle.[165] The president of Argentina's National Atomic Energy Commission has told the press: "We are trying to establish the best conditions to transfer the knowledge for making the fuel".[166] The growing trade deficit between Argentina and China is also becoming a problem, especially given the economic challenges Argentina is going through, and the Atucha-3 project has reportedly "hit a stumbling block over finances".[167] (See Annex 1 – section on Argentina.)

Renewable sources (not including large hydropower) produced 15.4 percent of the total electricity, over three times the contribution from nuclear power plants. Electricity produced by renewable sources increased by 19 percent in 2022[168] (see also Case Study on China in Nuclear Power vs. Renewable Energy Deployment).

China's renewable energy capacity continues to grow very rapidly. In June 2023, the official English-language communication platform of China's State Council announced that the country's installed capacity of non-fossil energy power generation now accounts for 50.9 percent of the total capacity.[169] The China Electricity Council reports an installed solar capacity of 392.6 GW and installed wind capacity of 365.4 GW as of the end of 2022, an annual

161 - Ramsey Al-Rikabi and Shawn Donnan, "U.S. Blacklists China Nuclear Firms Accused of Aiding Military", *Bloomberg*, 15 August 2019, see https://www.bloomberg.com/news/articles/2019-08-15/u-s-blacklists-china-nuclear-firms-accused-of-aiding-military, accessed 31 May 2020.

162 - Priyanka Shresta, "US blacklists Chinese nuclear firm involved in UK Hinkley Point C project", *Energy Live News*, 16 August 2019, see https://www.energylivenews.com/2019/08/16/us-blacklists-chinese-nuclear-firm-involved-in-hinkley-point-c-project/, accessed 17 August 2019; and Bureau of Industry and Security, "Addition of Certain Entities to the Entity List, Revision of Entries on the Entity List, and Removal of Entities From the Entity List", Department of Commerce, Federal Register, Vol. 84, No. 157, 14 August 2019, see https://www.govinfo.gov/content/pkg/FR-2019-08-14/pdf/2019-17409.pdf, accessed 29 September 2023.

163 - *WNN*, "China and Argentina sign nuclear project deal", *World Nuclear News*, 2 February 2022, see https://www.world-nuclear-news.org/Articles/China-and-Argentina-sign-nuclear-project-deal, accessed 2 February 2022.

164 - Phil Chaffee, "Atucha-3 EPC Contract Remains Conditional", Interview with Jose Luis Antunez, Nucleoeléctrica Argentina SA, *Nuclear Intelligence Weekly*, 11 February 2022.

165 - Vanessa Wolosz, "China's nuclear deal with Argentina slips again", *TMS*, 19 September 2022, see https://themilsource.com/2022/09/19/chinas-nuclear-deal-with-argentina-slips-again/, accessed 3 July 2023.

166 - Ibidem.

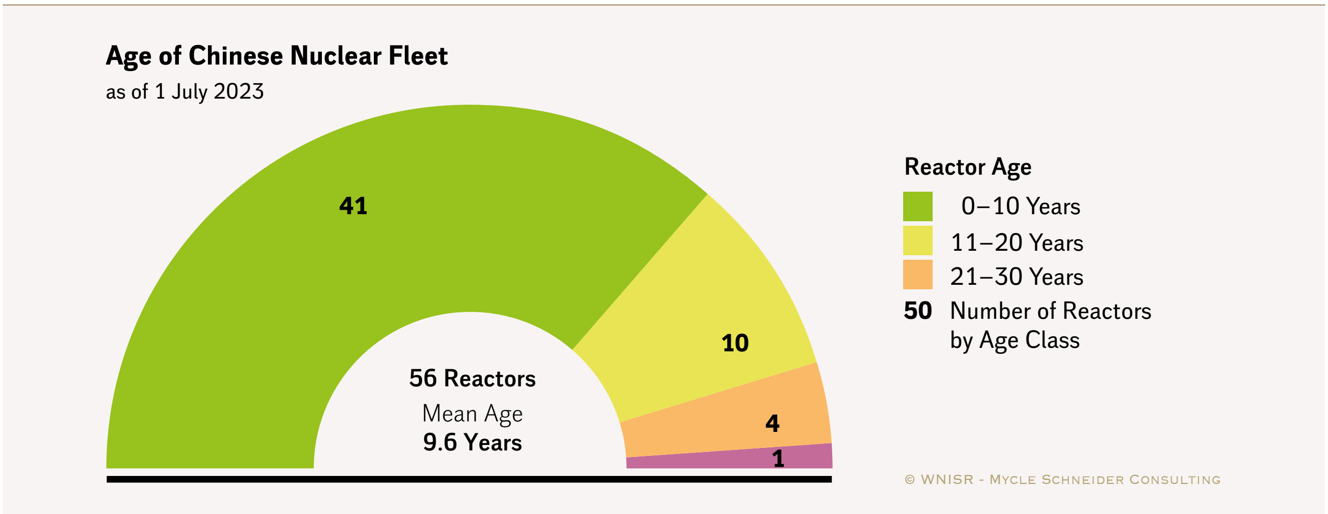
167 - Bala Chambers, "Argentina seeks to realign bilateral ties as trade deficit with China grows", *TRT World*, 1 March 2023, see https://www.trtworld.com/magazine/argentina-seeks-to-realign-bilateral-ties-as-trade-deficit-with-china-grows-12799142, accessed 3 July 2023.

168 - Energy Institute, "Statistical Review of World Energy", June 2023, op. cit.

169 - *CGTN*, "China's non-fossil fuel power generation capacity exceeds 50%", *China Global Television Network*, as published by State Council, People's Republic of China, 13 June 2023, see http://english.www.gov.cn/news/202306/13/content_WS6487c3cec6d0868f4e8dccc6.html, accessed 16 June 2023.

increase of 11.2 percent and 28.1 percent respectively.[170] The trend is accelerating. The installed capacity of solar projects that came online in the first quarter of 2023 was 155 percent above the same period in the previous year, with related investments going up 178 percent.[171]

Figure 27 • Age Distribution of the Chinese Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2023

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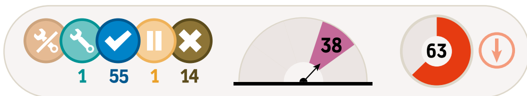


Overview

WNISR2022 pointed out that "2020 was considered 'particularly difficult for the French nuclear sector', but 2022 is likely to be significantly worse". It did turn out much worse, disastrous in fact, an "annus horribilis", according to nuclear utility EDF's Executive Director of Generation and Engineering of the Existing Nuclear and Thermal Fleet.[172] Nuclear output dropped below the level of 1990 when the installed nuclear capacity was some 5 GW lower. Nuclear generation actually peaked in 2005 at over 430 TWh and in nine of the following ten years, output exceeded 400 TWh, which was considered the norm until 2015. In 2022, French reactors produced 279 TWh, a drop of over 120 TWh from the 2005–2015 period.

To put this decline into perspective, it significantly exceeds the loss of 106 TWh of annual nuclear generation between the years 2010 and 2022 in Germany (see Germany Focus) due to the progressive decrease following the phaseout decision in 2011. The drop of over 150 TWh between France's historic peak nuclear generation of 430 TWh and the 2022-output exceeds

170 - CEC Statistics and Data Center, "2022年全国电力工业统计快报一览表" ["2022 National Statistical Snapshot of the Electricity Industry at a Glance"], China Electricity Council, 18 January 2023, see https://www.cec.org.cn/detail/index.html?3-317446, accessed 30 July 2023.

171 - Chint Solar, "Review on April 2023", as published on LinkedIn, 5 May 2023, see https://www.linkedin.com/pulse/review-april-2023-chintsolar/; and Anu Bhambhani, "China Installed 31 GW Solar PV In H1/2022", *TaiyangNews*, 21 July 2022, see https://taiyangnews.info/markets/china-installed-31-gw-solar-pv-in-h1-2022/; both accessed 30 July 2023.

172 - Cédric Lewandowski, EDF, Enquiry Committee Hearing at the National Assembly, 19 January 2023.

the annual average of 148 TWh of total nuclear electricity generated in Germany between 2001 and 2010. Germany's nuclear generation peaked at 162 TWh in 2001.

While nuclear production had increased by 7.5 percent in 2021 compared to 2020, the discovery in December of that same year of cracks in emergency core cooling systems led to the shutdown of the four largest (1500 MW) and most recent French reactors. The event represented an unexpected loss of 6 GW of capacity in the middle of the winter when consumption peaks in France. More than in any other European country, France has close to one third of the buildings using inefficient electric space heating. The four units did not generate a single kilowatt-hour throughout the year 2022.

Subsequently, it turned out that certain 1300-MW reactors—there are 20 such units—were also showing similar symptoms and, as of mid-2022, 12 reactors were shut down due to the problem. One of them, Penly-1, remained off-grid between October 2021 and July 2023.

Inspection techniques providing reliable results were a challenge. Inspections take time and it took until the end of July 2022 for the Nuclear Safety Authority (ASN) to judge EDF's inspection strategy "appropriate in the light of the knowledge acquired concerning the phenomenon and the corresponding safety issues".[173] Once defaults are detected, it takes time to fabricate replacement parts, and then do the replacement work. High profile, experienced nuclear welders are rare and there are many competing requirements for these specialists on the French nuclear fleet, including the construction site of the EPR at Flamanville, and there are significant radiation doses involved in the work that could quickly lead to regulatory exposure limits. Additional welders were flown in from Canada and the U.S., while replacement pipes were manufactured in Italy.[174] EDF intends to inspect the entire fleet of 56 reactors only by 2025.[175]

Concerns were growing over the year that a cold winter 2022–2023 could lead to power shortages, and even rolling blackouts were envisaged. For the first time since 1980, France turned into a net importer of electricity (16.7 TWh)[176] with Germany playing a key role exporting 15.3 TWh net.[177]

Following the discovery of the corrosion issue, on 13 January 2022, EDF published a downwards revised forecast for nuclear generation, and the French government announced the same day that it would force EDF to provide its competitors 20 percent more power, at fixed price, than

173 - ASN, "Stress corrosion phenomenon : ASN considers that EDF's inspection strategy is appropriate", 29 July 2022, see https://www.french-nuclear-safety.fr/asn-informs/news-releases/stress-corrosion-phenomenon-asn-considers-that-edf-s-inspection-strategy-is-appropriate, accessed 30 August 2022.

174 - *Energy News*, "Nuclear: after their reinforcement at EDF, the American welders pack up", 23 December 2022, see https://energynews.pro/en/nuclear-after-their-reinforcement-at-edf-the-american-welders-pack-up/; and Benjamin Mallet, "Focus: Welders wanted: France steps up recruitment drive as nuclear crisis deepens", *Reuters*, 29 November 2023, see https://www.reuters.com/business/energy/welders-wanted-france-steps-up-recruitment-drive-nuclear-crisis-deepens-2022-11-29/; and André Thomas, "Nucléaire : EDF épinglé par l'Autorité de sûreté pour des pièces sous-traitées en Italie", *Ouest France*, 5 January 2023 (in French), see https://www.ouest-france.fr/environnement/nucleaire/nucleaire-edf-epingle-pour-ses-tuyaux-italiens-f7c6aaac-8d18-11ed-8e30-162c8e51c813; all accessed 13 November 2023.

175 - EDF, "Groupe EDF—Rapport d'Activité 2022", 2023 (in French), see https://www.edf.fr/sites/groupe/files/2023-03/resultats-annuels-2022-rapport-activite-2023-03-06.pdf, accessed 13 November 2023.

176 - RTE, "Annual Electricity Review 2022", Réseau de Transport d'Électricité Français/French Transmission System Operator, 12 June 2023, see https://assets.rte-france.com/analyse-et-donnees/2023-08/Bilan%20%C3%A9lectrique%202022%20rapport%20GB_version_finale%20(2).pdf, accessed 13 November 2023.

177 - Fraunhofer ISE, "Energy Charts", Updated 27 October 2023, see https://Energy-Charts.info, accessed 13 November 2023.

expected—120 TWh instead of 100 TWh—to limit the effect of sky-rocketing market prices for the consumer. The move indeed limited the price increase of the regulated tariff to 4 percent instead of over 40 percent but significantly contributed to EDF's catastrophic 2022-results with a negative impact estimated at €8.34 billion (US$$_{2023}$8.80 billion).[178]

As early as July 2022, some estimates put EDF's expected net debt as high as €65 billion (US$$_{2022}$68 billion) at year-end,179 and the government announced it would hit the emergency brake and fully re-nationalize EDF. The estimates proved extraordinarily precise, as net debt grew by 50 percent to reach €64.5 billion (US$$_{2022}$67.9 billion) at year-end, and €64.8 billion (US$$_{2023}$70 billion) at mid-2023, according to EDF's financial results.[180]

This chapter does not even cover complex fuel chain issues, climate impact, and social movements. The plutonium-economy part of the industry is experiencing its own—underreported—crisis. The throughput of the equally ageing spent fuel reprocessing plant at La Hague dropped to 925 tons in 2022 (for a licensed capacity of 1,700 tons per year), a level last seen in the early 1990s. Consequently, the spent fuel pools are nearing saturation. The project to build a large new cooling pool is encountering fierce local opposition. The uranium-plutonium mixed-oxide (MOX) fuel fabrication facility MELOX at Marcoule plummeted to below 60 tons per year in 2021–2022, that is below 30 percent of its licensed capacity.[181] Consequently, the stocks of unirradiated plutonium have increased to the unprecedented level of 92 tons, an increase of spectacular 24 tons since 2018.[182]

All of these new challenges for an already strained industry did not prevent the National Assembly from picking up on the French President's landmark "nuclear renaissance" speech of 10 February 2022 and in June 2023 passing legislation for the "acceleration of procedures for the construction of new nuclear facilities near existing nuclear sites and for the operation of existing facilities".[183] The President had expressed his "wish" that "six EPR2 be built and that we launch the studies for the construction of eight additional EPR2".[184]

The new law requires the government, prior to tabling legislation on the next pluriannual energy planning, to transmit to Parliament a report that assesses the consequences of the construction of 14 nuclear power reactors on the nuclear industry, the electricity market, and public finances; on nuclear safety and security; on the nuclear fuel chain; and on the means of the Local Information Commissions (CLI). The law simplifies certain administrative procedures, decrees that a nuclear power reactor automatically "constitutes an imperative

178 - EDF, "Comptes Consolidés au 31 décembre 2022", 16 February 2023.

179 - Christine Kerdellant, "Nationaliser EDF : pour quoi faire ?", *Les Echos*, 8 July 2022 (in French), see https://www.lesechos.fr/idees-debats/editos-analyses/nationaliser-edf-pour-quoi-faire-1775293, accessed 30 August 2022.

180 - EDF, "Comptes Consolidés au 31 décembre 2022", 16 February 2023.

181 - Orano, "Bilan ORANO pour CLI pour mise à jour au 31 12 2022", 6 March 2023, Unpublished.

182 - French Government declarations to the IAEA, INFCIRC/549/Add.5, 1995-2023, compiled by Mycle Schneider Consulting, November 2023.

183 - French Government, "LOI no 2023-491 du 22 juin 2023 relative à l'accélération des procédures liées à la construction de nouvelles installations nucléaires à proximité de sites nucléaires existants et au fonctionnement des installations existantes", enacted 22 June 2023, *Journal Officiel de la République Française*, promulgated 23 June 2023 (in French), see https://www.legifrance.gouv.fr/download/pdf?id=32HzSNCPyz8WLoK-WsqAqoiX_erjixoTD_Jy3AVXRFk=, accessed 3 November 2023.

184 - Presidency of the French Republic, "Reprendre en main notre destin énergétique !", Speech by President Emmanuel Macron (in French), Elysée, French Government, 10 February 2022, see https://www.elysee.fr/emmanuel-macron/2022/02/10/reprendre-en-main-notre-destin-energetique, accessed 30 August 2022.

reason of major public interest" and dilutes some environmental protection rules. For example, a new nuclear power reactor will not be considered in local limitation targets for soil artificialization or consumption of natural, agricultural, or forest areas.[185]

Currently, the EPR2 does not even exist on the drawing board; no detailed design is available yet. The government administration estimated in an October 2021 internal note that 19 million engineering hours still had to be deployed to get from "basic design" to the "detailed design" stage and that, if everything goes well, the first EPR2 could start up by 2039–2040. In case unexpected industrial difficulties occur—as they did in the past and do currently—it could take until 2043 to commission the first EPR2, the project review states.[186]

Largely unreported, the science community in France is far from offering unanimous support of the newbuild initiative. As of the end of October 2023, close to 1,200 scientists, doctors, teachers, engineers, academics, and researchers had signed "Call by scientists against a new nuclear program" claiming:

> ...with neither a real democratic debate, nor a serious assessment of past choices and the options available today, our leaders are preparing to relaunch a program of construction of new nuclear power stations. Under the pretext of the climate emergency, but on the basis of truncated, simplistic, even grossly erroneous arguments, lobbyists with significant media influence are working to organize amnesia of nuclear disasters and revise history. (...)
>
> In the immediate future, the industrial and financial efforts that this new program would require, would for a long time monopolize the financial and human resources necessary to face the combined challenges of the climate crisis, the collapse of biodiversity, generalized pollution and resource depletion.[187]

In addition to the national initiatives to relaunch the nuclear sector, the French government has been leading a large group of a dozen E.U. countries to collectively lobby the European institutions to create favorable conditions for the nuclear industry in the process of the restructuring of the European electricity market and of the definition of various legislative tools of European climate policy. Much of these negotiations are still ongoing and the outcome will likely be a compromise with a group of countries led by Germany strongly favoring a strategy based on sufficiency, efficiency, and renewable energies.

Another Worst Performance in Decades

Until the closure of the two oldest French units at Fessenheim in the spring of 2020, the French nuclear fleet had remained stable for 20 years, except for the closure of the 250 MW fast breeder Phénix in 2009, two units in Long-Term Outage (LTO) within the period 2015–2017, and another one within the period 2021–2023 (see Figure 28). Penly-1, subject to the stress-

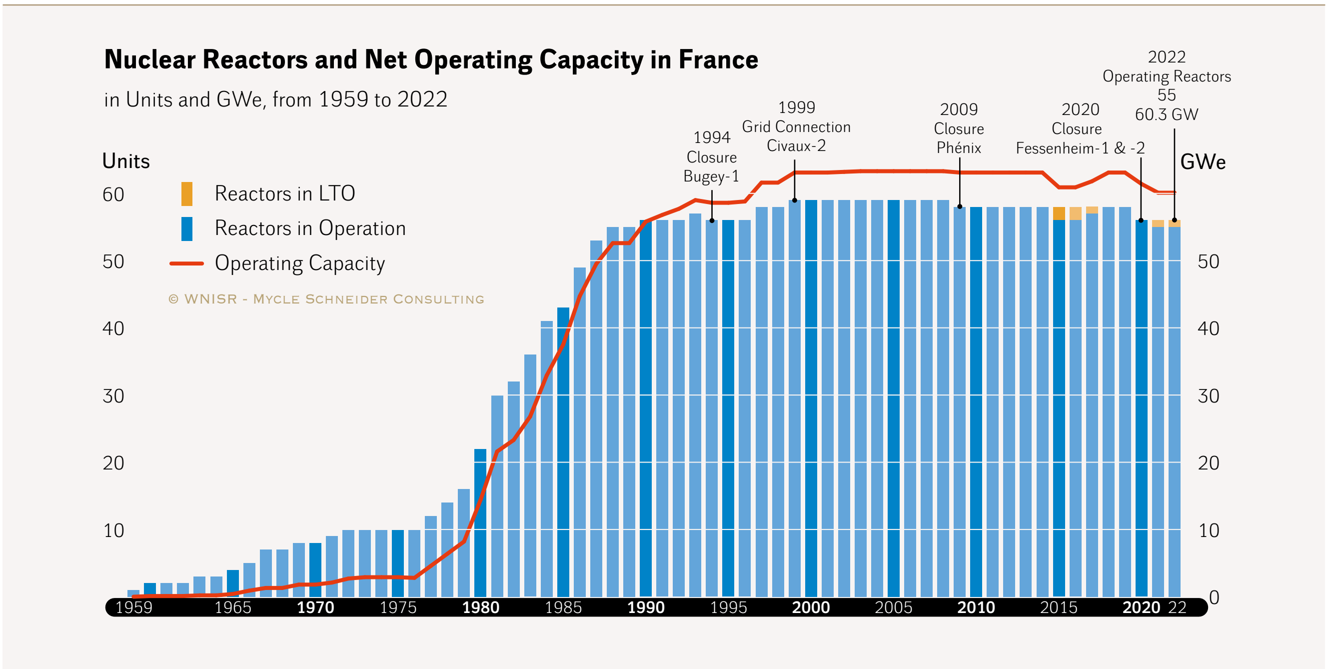
185 - *JORF*, "LOI no 2023-491 du 22 juin 2023 relative à l'accélération des procédures liées à la construction de nouvelles installations nucléaires à proximité de sites nucléaires existants et au fonctionnement des installations existantes", 23 June 2023, op.cit.

186 - French Government, "Travaux relatifs au nouveau nucléaire—PPE 2019-2028", as published by *Contexte* (in French), October 2021, see https://www.contexte.com/article/energie/info-contexte-nucleaire-pas-encore-lances-les-futurs-epr-deja-en-retard-et-plus-chers_140631.html, accessed 30 August 2022.

187 - Group of Scientists for Information on Nuclear Energy, Global Chance et al., "Call by scientists against a new nuclear program", June 2023, see https://appel-de-scientifiques-contre-un-nouveau-programme-nucleaire.org/en/, accessed 5 November 2023.

corrosion cracking issue, was offline between 2 October 2021 and 13 July 2023.[188] While the four units at Civaux and Chooz-B did not generate power throughout 2022, they did not meet the LTO criteria as they were restarted prior to mid-2023.

Figure 28 · Operating Fleet and Capacity in France

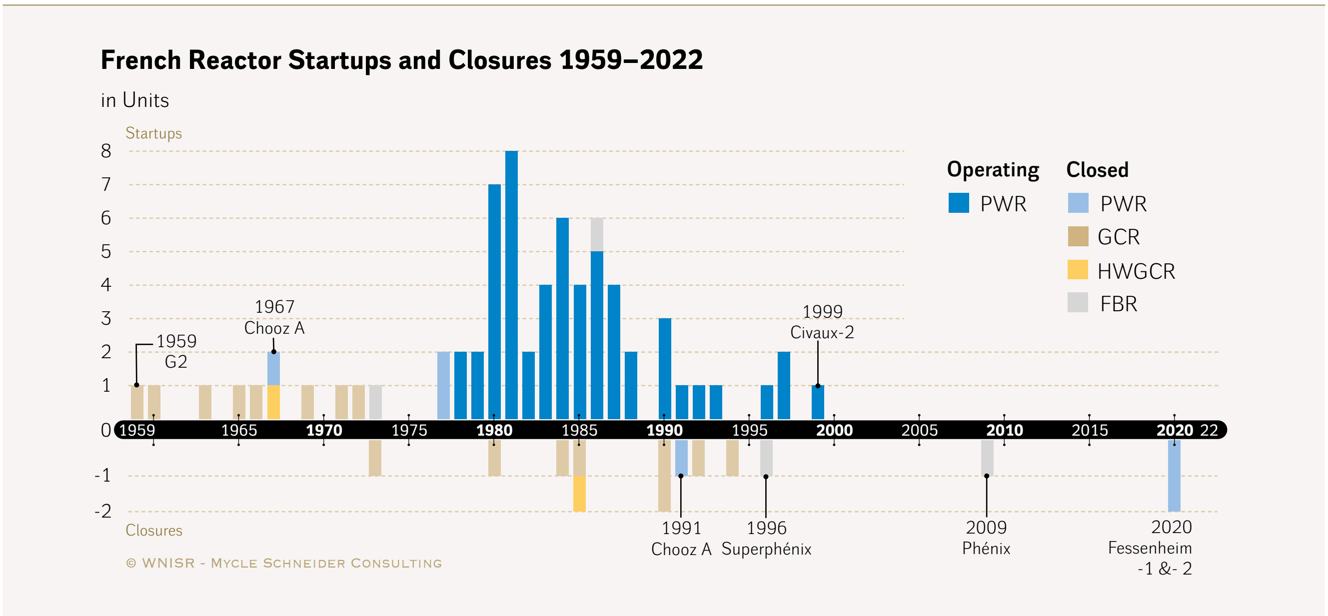


Sources: WNISR with IAEA-PRIS, 2023

No new reactor has started up since Civaux-2 was connected to the French grid in 1999. The first and only PWR closed prior to Fessenheim was the 300-MW Chooz-A reactor, which was retired in 1991. The other closures were eight first-generation natural-uranium gas-graphite reactors, two fast breeder reactors and a small prototype heavy water reactor (see Figure 29).

188 - EDF, "Les deux unités de production de la centrale nucléaire de Penly connectées au réseau électrique national", 13 July 2023 (in French), see https://www.edf.fr/la-centrale-nucleaire-de-penly/les-actualites-de-la-centrale-nucleaire-de-penly/les-deux-unites-de-production-de-la-centrale-nucleaire-de-penly-connectees-au-reseau-electrique-national, accessed 1 November 2023.

Figure 29 • Startups and Closures in France



Sources: WNISR, with IAEA-PRIS, 2023

Notes: **PWR**: Pressurized Water Reactor; **GCR**: Gas-Cooled Reactor; **HGWGCR**: Heavy Water Gas Cooled Reactor; **FBR**: Fast Breeder Reactor.

In 2022, the 56-reactor fleet[189]—of which one in LTO and four that did not generate any power but did not meet the LTO criteria—produced 279 TWh[190], a drop of 22.7 percent over the previous year; nuclear generation was below 300 GW for the first time since 1990, and the seventh year in a row that it remained below 400 TWh. Grid operator RTE stated:

> **This was the first time since the construction of the existing nuclear fleet was completed that annual output was this low, falling 30% below the average of the prior 20 years.** In absolute terms, it is the lowest level on record since 1988, when installed nuclear capacity in France stood at just 51 GW, or 83% of today's total capacity (eight fewer reactors).[191] [bold emphasis in original]

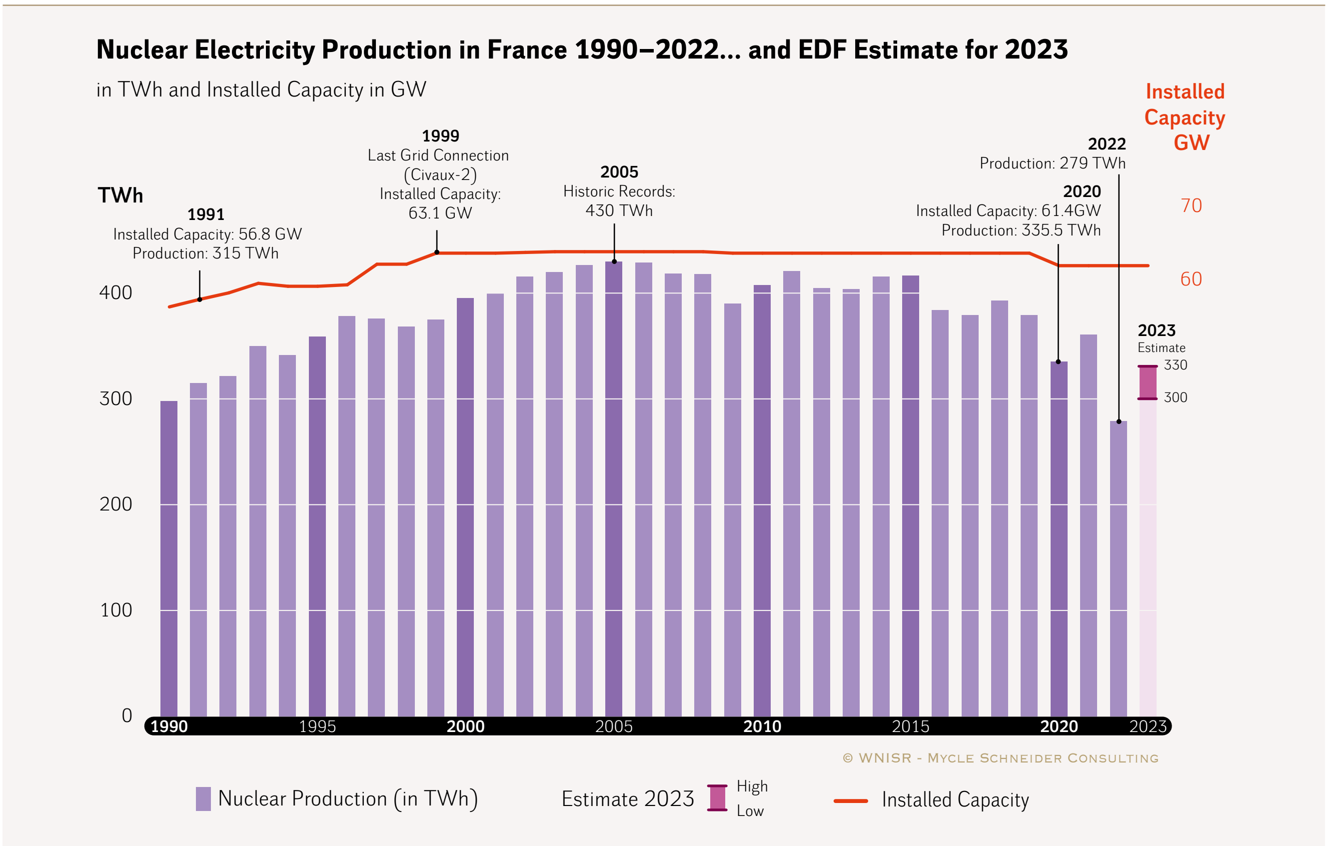
In 2005, nuclear generation peaked at 431.2 TWh. It took the fleet five years to build up to that maximum generation, and with a quasi-stable installed nuclear capacity between late 1999 and early 2020, performance plunged after 2015 (see Figure 30).

189 - All Pressurized Water Reactors (PWRs), 32 x 900 MW, 20 x 1300 MW, and 4 x 1400 MW.

190 - RTE, "Annual Electricity Review 2022", 12 June 2023, op.cit.

191 - RTE, "Annual Electricity Review 2022—Key Findings", June 2023, see https://analysesetdonnees.rte-france.com/en/electricity-review-keyfindings, accessed 13 November 2023.

Figure 30 • Nuclear Electricity Production vs. Installed Capacity in France, 1990–2023



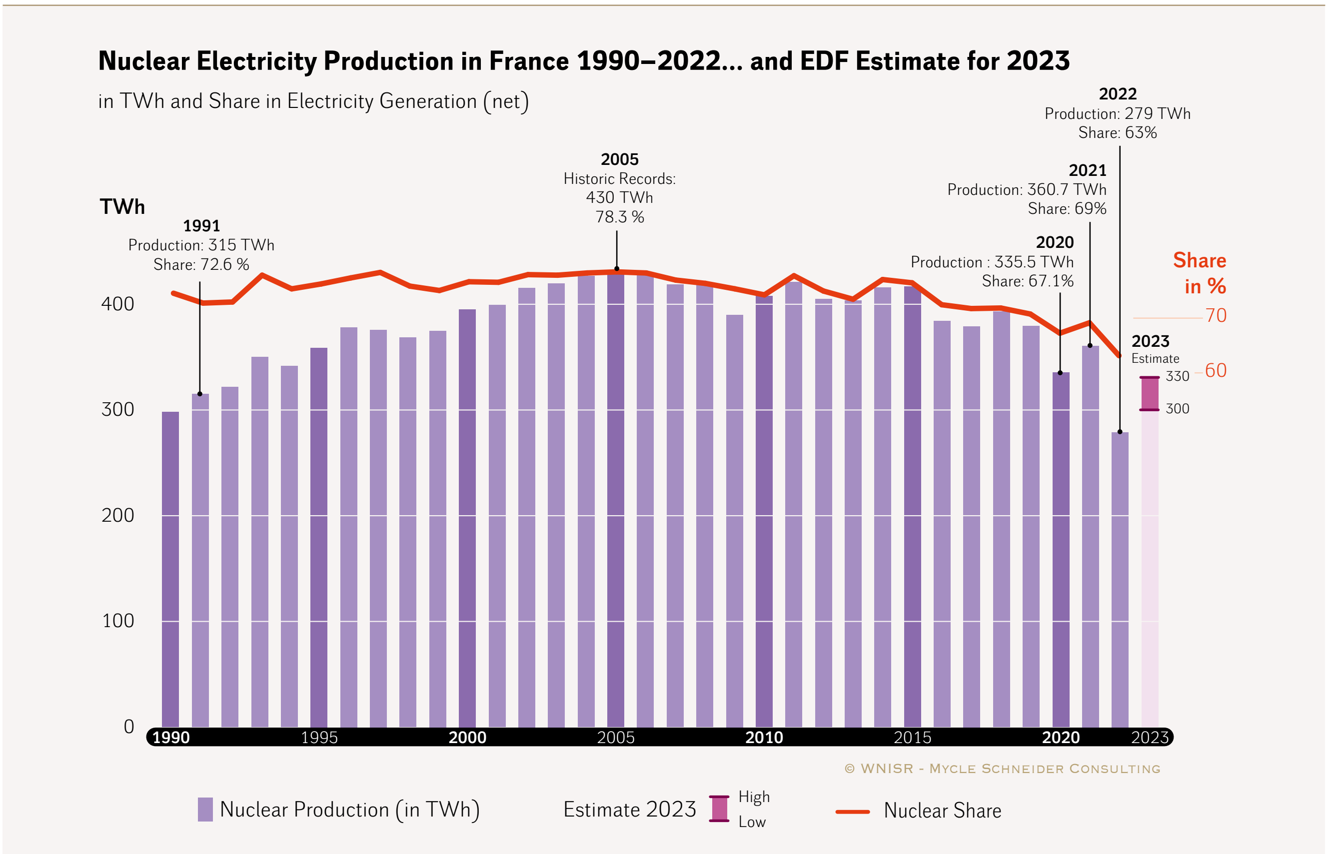
Sources: RTE, 2000–2023, EDF 2023

Note: In Figure 30, reactors in LTO are counted in the "installed capacity".

In 2022, nuclear plants provided 62.7 percent (–6.3 percentage points) of the country's electricity, even less than in 2020. According to RTE, the nuclear share peaked in 2005 at 78.3 percent. As of mid-2023, EDF estimates the production range for the year at 300–330 TWh, for 2024 at 315–345 TWh and for 2025 at 335–365 TWh[192] (see Figure 30 and Figure 31).

192 - EDF, "2023 Half-Year Results", Press Release, 27 July 2023, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/2023-half-year-results-substantially-higher-ebitda-and-stabilisation-of-net-financial-debt-gradual-return-to-better-nuclear-fleet-availability-good-overall-operational-performance, accessed 4 September 2023.

Figure 31 • Nuclear Electricity Production vs. Nuclear Share in France, 1990–2023



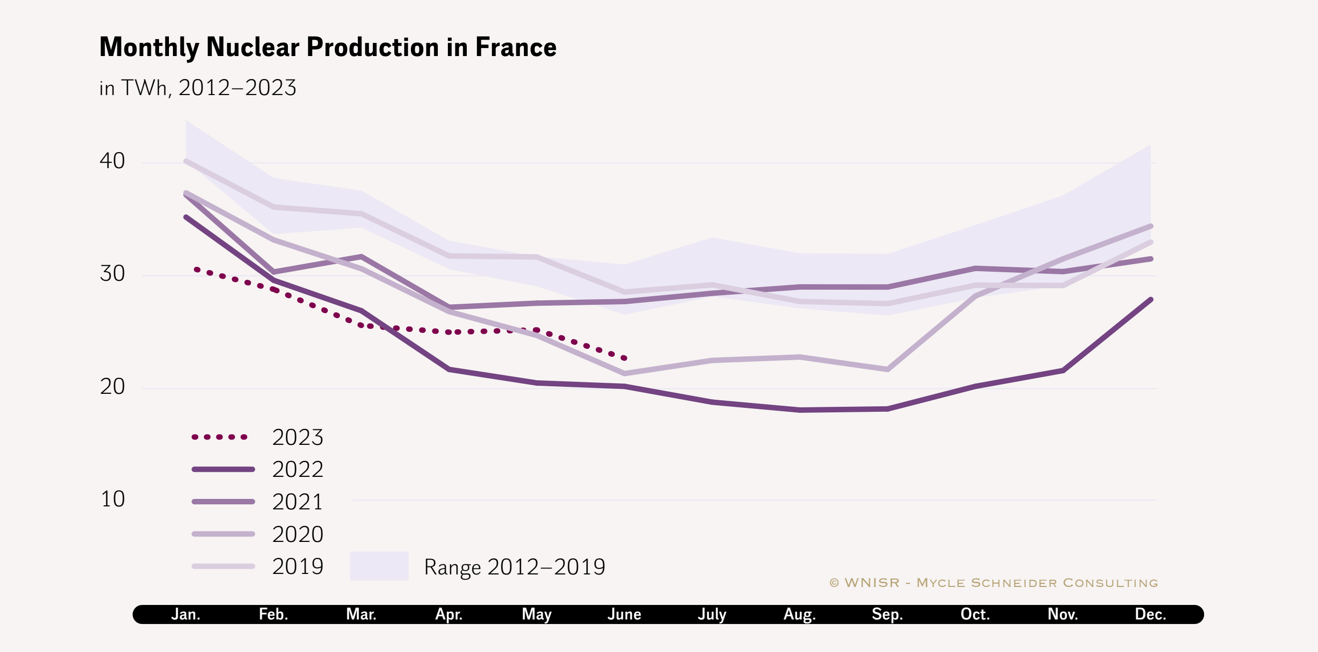
Sources: RTE, 2000–2023, EDF 2023

Monthly production has continued to deteriorate in early 2023 with a lower output in every month of the first quarter of the year than in any year over the past decade, and while output significantly improved in the second quarter, it remained below the 2021 level (see Figure 32).

Electricity represented 25 percent of final energy in France in 2022. As nuclear plants provided 62.7 percent of electricity, nuclear plants covered 15.7 percent of final energy. The largest share being covered by fossil fuels at over 60 percent, with oil at 42.9 percent and natural gas at 17.4 percent (coal <1 percent), while renewables contributed only 11.1 percent just as in the previous year.[193]

193 - Ministry of Energy Transition, "Bilan énergétique de la France en 2022 – Données provisoires", Ministère de la Transition Énergétique, French Government, April 2023 (in French), see https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2023-04/datalab_essentiel_306_bilan_energetique_provisoire_2022_avril2023_1.pdf, accessed 13 November 2023.

Figure 32 • Monthly Nuclear Electricity Generation, 2012–mid-2023



Sources: RTE and EDF, 2021–2023[194]

Nuclear Unavailability Review 2022

In 2022, there were 8,515 reactor-days—an increase of 2,704 reactor-days or +46.5 percent compared to 2021—an average of 152 days with zero-production per reactor. This does not include load following or other operational situations with reduced output but above-zero. The number is 58 percent higher than the average 96 days per reactor in pre-COVID year 2019, and 32 percent higher than in 2020 (see Table 5). All 56 reactors were subject to outages lasting four to 365 days (see Figure 35). Five reactors were offline during the whole year. Over half of the French nuclear reactor fleet (29 units) was not available during at least one third of the year, including one third (18 units) that was not available for more than half of the year.

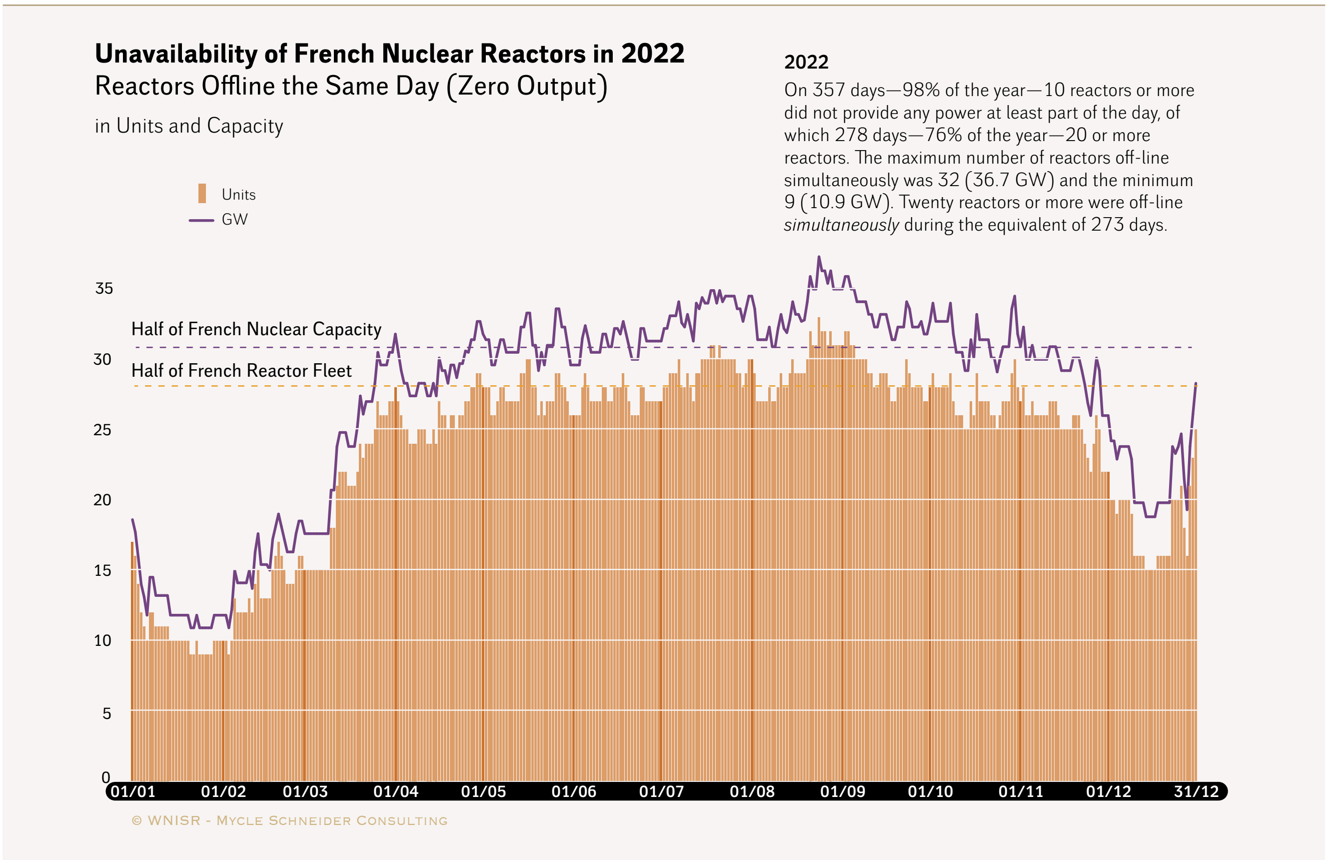
194 - RTE, "Données Mensuelles" and EDF "Nuclear Generation", 2021–2023, see https://www.edf.fr/en/the-edf-group/dedicated-sections/investors/financial-and-extra-financial-performance/operational-performance/nuclear-generation.

Table 5 · Total Unavailability at French Nuclear Reactors, 2019–2022 (in Reactor-Days)

	Declared Type of Unavailability			
	"Planned"	Forced	Total	Average per Reactor
2019	5,273	316	5,588	96
2020	6,179	286	6,465	115
2021	5,639	172	5,811	104
2022	8,287	278	8,515	152

Sources: RTE and EDF REMIT Data, 2019–2023

Figure 33 · Reactor Outages in France in 2022



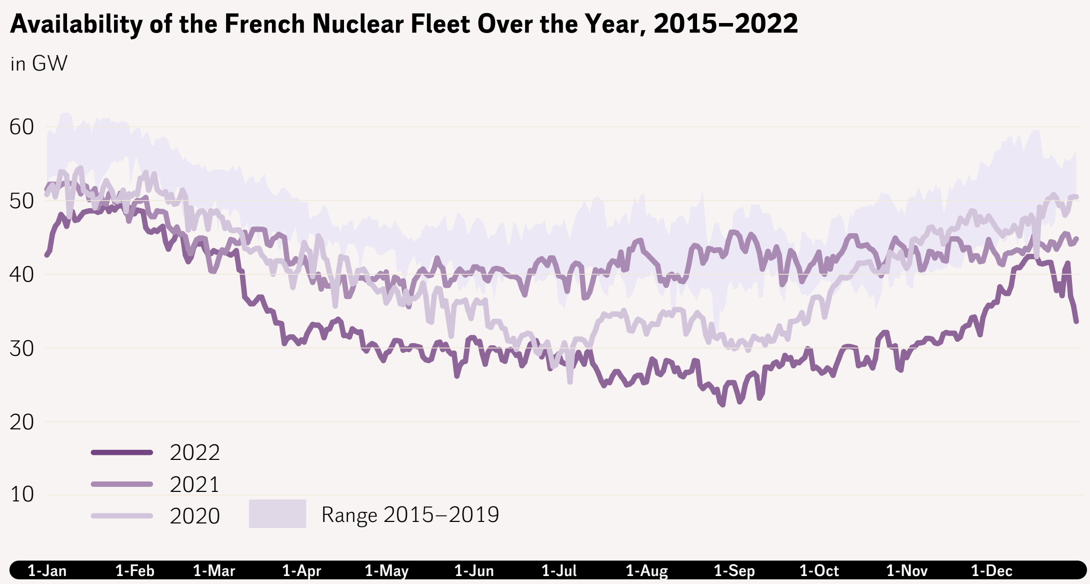
Sources: compiled by WNISR, with RTE and EDF REMIT Data, 2021–2023

Note: For each day in the year, this graph shows the total number of reactors offline, not necessarily simultaneously as all unavailabilities do not overlap, but on the same day.

The unavailability analysis for the year 2022 on Figure 33 further shows:

- On 357 days (98 percent of the year), at least 10 units and up to 34 were down during the same day.
- On 280 days (77 percent of the year), 19 or more units were shut down for at least part of the day.
- At least nine reactors were down (zero capacity) *simultaneously* at any day of the year.
- At least 20 reactors were offline *simultaneously* during the equivalent of 273 days.
- On 22 August 2023, a total of 33 reactors, or 59 percent of the fleet, was offline.

Figure 34 · Availability of the French Nuclear Fleet Over the Year, 2015–2022



Sources: RTE, 2023[195]

RTE provides a monthly availability analysis (see Figure 34) with the following comments:

> The availability of France's nuclear fleet was historically low throughout 2022, with a yearly average availability of 54% compared with an average of 73% between 2015 and 2019.
>
> An **all-time low of 21.7 GW was recorded on 28 August 2022**, when nearly **65% of the fleet** [capacity] **was offline**. [bold emphasis in original] (...)
>
> The gap with prior years was particularly pronounced during the summer, which saw a concentration of unscheduled outages following the discovery, in late-2021, of stress corrosion cracking in several reactors. These outages, or outage extensions to carry out maintenance, tests and repairs where needed, primarily involved the newest reactors in the fleet (N4 and P4' designs), i.e. reactors that were not targeted for investment in the Grand Carénage refit programme. These additional outages added to an already busy operational

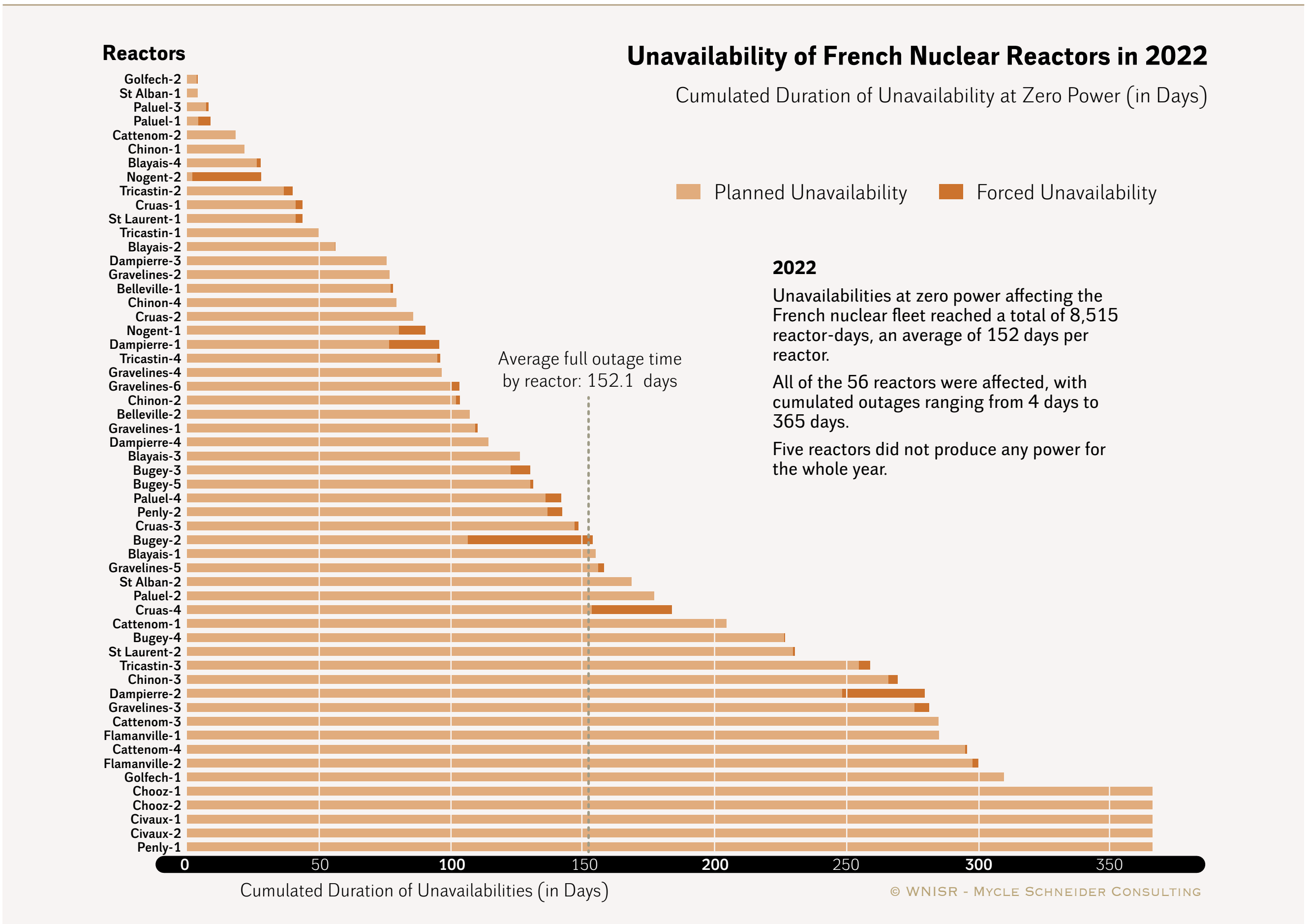
195 - RTE, "Annual Electricity Review 2022—Key Findings", June 2023, op. cit..

calendar made even busier by the postponements of maintenance caused by the COVID-19 crisis.[196]

According to EDF's classification of "planned" and "forced" unavailabilities, in 2022:

- 24 reactors did not experience any "forced" outage,
- at eight units "forced" outages lasted less than one day,
- at 18 their cumulated duration represented between one and ten days,
- and at five reactors "forced" outage cumulated between 18.8 and 47 days over the year (see Figure 35).

Figure 35 · Forced and "Planned" Unavailability of Nuclear Reactors in France in 2022



Sources: compiled by WNISR, with RTE and EDF REMIT Data, 2021–2023

Notes: This graph only compiles outages at zero power, thus excluding all other operational periods with reduced capacity >0 MW. Impact of unavailabilities on power production is therefore significantly larger.

"Planned" and "Forced" unavailabilities as declared by EDF.

196 - Ibidem.

However, EDF's declaration of "planned" vs. "forced" outages is highly misleading. EDF considers an outage as "planned" whatever the number and length of extensions (or, in rare cases, reductions) of its total duration if the outage was first declared as "planned".

Detailed WNISR analysis for earlier years shows a different picture.

"Unplanned unavailability added up to 1,330 days, an increase of 30 percent beyond the expected outage durations."

The complete assessment of 240 outages in 2021, shows that 161 were declared "planned" and 79 "forced". In the case of "forced" outages, a generic duration of one day was first declared in most cases (75 percent) and is then readjusted. The additional duration of "forced" outages represented less than 100 days. For "planned" outages, additional unplanned unavailability represented 1,238 days that EDF nevertheless labeled as "planned". In fact, almost 25 percent of the full-outage durations were unplanned.

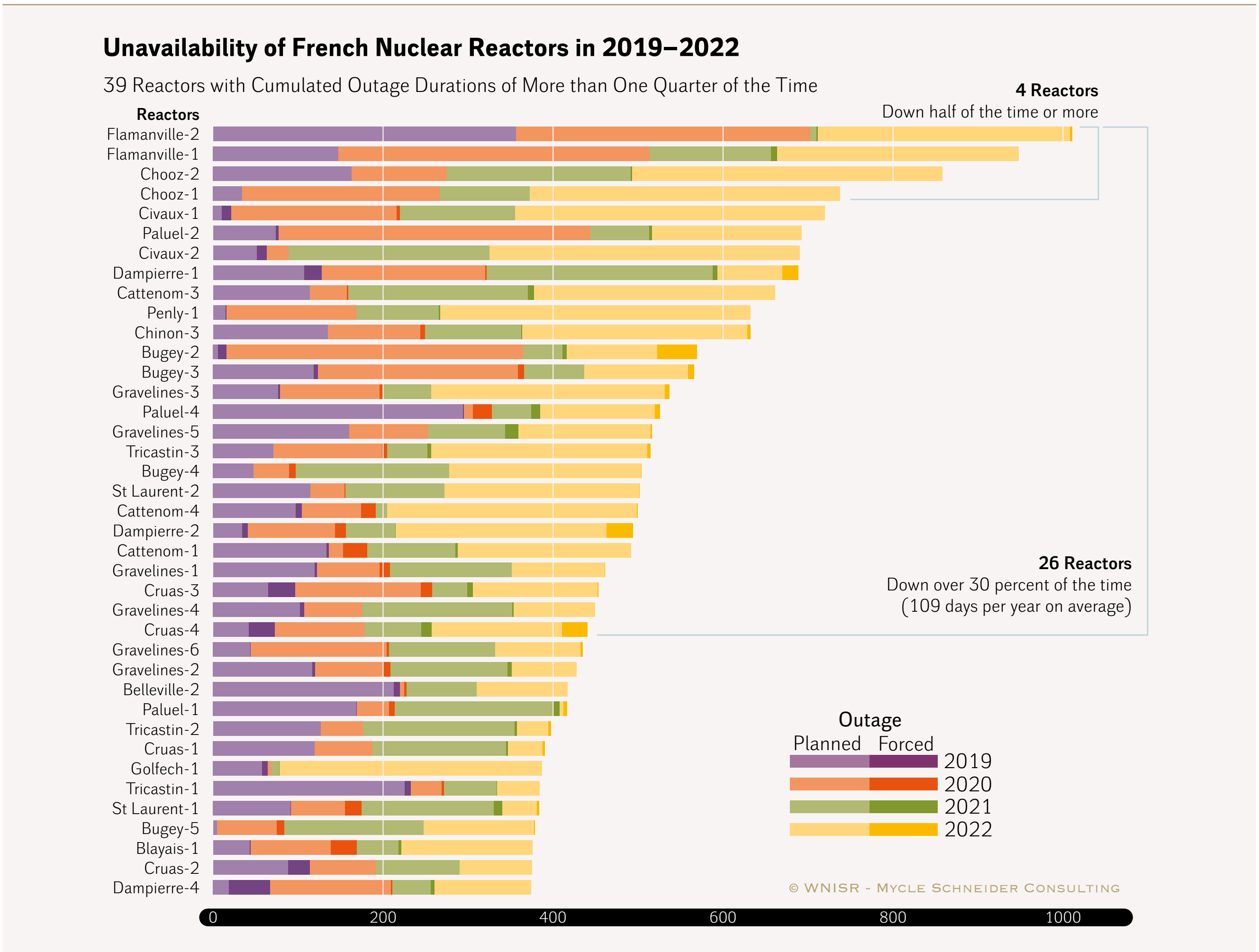
Of the 240 full outages, 86 experienced a prolongation exceeding 1 day and up to 156 days (Chooz-2) in 2021[197]; the cumulated prolongation over the year was over 1,500 days. On the other side, 18 outages were shorter than planned by at least one day; the cumulated reduction over the year was 171 days. (These cases are likely due to outage re-scheduling rather than net savings of outage days.) As a result, the net additional unplanned unavailability added up to 1,330 days, an increase of 30 percent beyond the expected outage durations.

The cumulated outage analysis over the four years 2019–2022 reveals the following (see Figure 36):

- Four reactors were down half of the time or more (Flamanville-1 and -2, Chooz-1 and -2);
- 26 reactors were generating zero power for 30 percent of the time, that is 109 days and more per year on average.
- 39 reactors were off-grid for at least one quarter of the time, in other words, they did not generate any power for the equivalent of one in four years.

197 - In case a reactor was shut down in 2020 and due to be back on-line prior to 31 December 2020, the outage duration in 2021 is entirely considered as extended unavailability.

Figure 36 • Unavailability of a Selection of French Nuclear Reactors, 2019–2022



Sources: compiled by WNISR, with RTE and EDF REMIT Data, 2019–2023

Note: The categorization follows EDF's classification. However, it is not reflecting reality as a "planned" outage remains in that category even if it lasts much longer than "planned".

Status of Stress Corrosion Cracking Issue

Severe stress corrosion cracking had been first identified in late 2021 at the safety injection systems of the four largest and most recent French reactors at Chooz and Civaux.[198] Later additional reactors were identified and a program of pre-emptive replacement of particularly sensitive piping sections was decided for the "P'4" reactor series. While apparently so far rare, the phenomenon has also been identified on other 1300-MW and some 900-MW reactors (see Table 6 for details). EDF decided to inspect its entire reactor fleet by the end of 2025.

In February 2023, an additional issue has been identified during destructive examination at Penly-1. Close to a weld of a line of the safety injection system that had been repaired during construction of the plant, a 15.5 cm long—about one quarter of the circumference—and up to

198 - ASN, "Phénomène de corrosion sous contrainte détecté sur les réacteurs 1 et 2 de Civaux, B2 de Chooz et 1 de Penly", Information Notice (in French), 31 January 2022, see https://www.asn.fr/l-asn-informe/actualites/phenomene-de-corrosion-sous-contrainte-detecte-sur-certains-reacteurs, accessed 13 November 2023.

2.3 cm deep crack—for a 2.7 cm thick tube—was identified. The origin has been determined as thermal fatigue rather than stress corrosion cracking. This discovery meant that an extensive inspection program of all repaired welds had to be added to the stress corrosion cracking investigations. According to planning, 90 percent of the repaired welds in the safety injection and shutdown cooling systems of the entire reactor fleet are to be inspected until the end of 2024 with the remaining ones in 2025.[199]

According to EDF, as of mid-2023, 11 of the 16 reactors identified as most sensitive to stress corrosion—the four 1500-MW units and 12 P'4 1300-MW reactors—had been repaired or preemptively treated while two, Cattenom-1 and Bellevillle-2, were undergoing repairs, and two more, Belleville-1 and Nogent-1, were to be fixed before the end of the year. The remaining unit, Cattenom-4, is to be repaired during its fourth 10-year inspection.[200]

Table 6 · Stress Corrosion Cracking - Inspected and Repaired Reactors (as of 30 June 2023)

Reactor Design	Reactor	Improved Ultrasonic Inspections	Repairs	Preventive Piping Replacements
1450 MW N4	Chooz-1	Completed		Completed
	Chooz-2	Completed		Completed
	Civaux-1	Completed		Completed
	Civaux-2	Completed		Completed
1300 MW P'4	Belleville-1	Upcoming		Upcoming
	Belleville-2	Ongoing		Ongoing
	Cattenom-1	Ongoing		Ongoing
	Cattenom-2	Completed		Completed
	Cattenom-3	Completed		Completed
	Cattenom-4			Upcoming
	Golfech-1	Completed		Completed
	Golfech-2	Ongoing		Completed
	Nogent-1	Upcoming		Upcoming
	Nogent-2	Completed		Completed
	Penly-1	Completed		Completed
	Penly-2	Completed		Completed
1300 MW P4	Flamanville-1	Completed	Ongoing	
	Flamanville-2	Completed	Completed	
	Paluel-1	Completed		
	Paluel-2			
	Paluel-3	Ongoing		
	Paluel-4			
	St Alban-1	Ongoing		
	St Alban-2			
900 MW CP0	Bugey-2	Upcoming		
	Bugey-3	Upcoming		
	Bugey-4		Completed	
	Bugey-5	Completed		

199 - EDF, "Le phénomène de corrosion sous contrainte sur les circuits auxiliaires du CPP – État des lieux actualisé", presented 4 July 2023 (in French), see https://www.anccli.org/wp-content/uploads/2023/07/Webinaire-CSC_2023-07-04_01-Etat-des-lieux_EDF.pdf, accessed 2 November 2023.

200 - Ibidem.

Reactor Design	Reactor	Improved Ultrasonic Inspections	Repairs	Preventive Piping Replacements
900 MW CP1	Blayais-1	Completed		
	Blayais-2	Upcoming		
	Blayais-3			
	Blayais-4	Completed		
	Dampierre-1	Completed		
	Dampierre-2	Completed		
	Dampierre-3	Upcoming		
	Dampierre-4			
	Gravelines-1	Completed		
	Gravelines-2	Ongoing		
	Gravelines-3	Completed		
	Gravelines-4			
	Gravelines-5			
	Gravelines-6	Completed		
	Tricastin-1	Upcoming		
	Tricastin-2	Ongoing		
	Tricastin-3	Completed	Completed	
	Tricastin-4			
900 MW CP2	Chinon-1	Ongoing		
	Chinon-2			
	Chinon-3	Ongoing	Completed	
	Chinon-4			
	Cruas-1	Ongoing		
	Cruas-2	Upcoming		
	Cruas-3			
	Cruas-4			
	St Laurent-1	Upcoming		
	St Laurent-2	Ongoing		

Source: EDF, 2023[201]

Note: CP0, CP1, CP2, P4, P'4, and N4 designate identical (or almost) design series of reactors.

Lifetime Extension – Fact Before License

By mid-2023, the average age of the 56 nuclear power reactors exceeds 38 years (see Figure 37). Lifetime extension beyond 40 years—51 operating units are now over 31 years old of which 20 are over 41 years—requires significant additional upgrading. Also, relicensing is subject to public inquiries reactor by reactor.

EDF will likely seek lifetime extension beyond the 4th Decennial Safety Review (VD4) for most, if not all, of its remaining reactors. President Macron in his February 2022 programmatic speech made it clear that the government has no intention of closing reactors anymore. He stated: "While the first extensions beyond 40 years have been implemented successfully since 2017, I'm asking EDF to examine the conditions of the [lifetime] extensions beyond 50 years, in conjunction with the nuclear safety authority".[202]

201 - EDF, "Le phénomène de corrosion sous contrainte sur les circuits auxiliaires du CPP – État des lieux actualisé", July 2023, op. cit.

202 - French President Emmanuel Macron, "Reprendre en main notre destin énergétique !", 10 February 2022, op. cit.

The first reactor to undergo the VD4 was Tricastin-1 in 2019. Bugey-2 and -4 were scheduled in 2020, and Tricastin-2, Dampierre-1, Bugey-5 and Gravelines-1 started in 2021… until the COVID-19 pandemic further disrupted the safety review schedule.[203] Until mid-2023, 11 units had undergone their VD4 and a further five were underway (see Table 7).

While the President of the Nuclear Safety Authority (ASN) judged the VD4-premiere on Tricastin-1 "satisfactory", he questioned whether EDF's engineering resources were sufficient to carry out similar extensive reviews simultaneously at several sites.[204] Beyond the human resource issue, the experience raises the question of affordability. EDF had scheduled an outage for Tricastin-1 of 180 days in 2019, which was first extended by 25 days to 205 days. Including further, unrelated unavailabilities, the reactor was finally in full outage for two thirds of that year (232 days).

Table 7 · Fourth Decennial Visits of French 900-MW Reactors, 2019–2023

Reactor	Capacity	Grid Connection	VD4 Outage	Expected Duration (in days)	Total Duration (in days)
Tricastin-1	915	31 May 1980	01/06/19–23/12/19	180	205
Bugey-2	910	10 May 1978	18/01/20–15/02/21	181	395
Bugey-4	880	8 March 1979	22/11/20–24/06/21	226	214
Dampierre-1	890	23 March 1980	19/06/21–05/02/22	170	231
Tricastin-2	915	7 August 1980	06/02/21–26/07/21	180	170
Bugey-5	880	31 July 1979	31/07/21–21/04/22	189	265
Gravelines-1	910	13 March 1980	14/08/21–11/04/22	188	240
Tricastin-3	915	10 February 1981	12/03/22–21/11/22	171	254
Gravelines-3	910	12 December 1980	23/03/22–22/12/22	191	275
Dampierre-2	890	10 December 1980	27/04/22–31/12/22	171	248
Blayais-1	910	12 June 1981	31/07/22–19/06/23	185	323
Saint-Laurent-2	915	1 June 1981	20/01/23–15/11/23**	223	299**
Chinon B-1	905	30 November 1982	07/02/23–29/01/24**	265	356**
Gravelines-2	910	26 August 1980	10/06/23–24/12/23*	197	
Blayais-2	910	17 July 1982	24/06/23–23/12/23*	182	
Dampierre-3	890	30 January 1981	24/09/23-11/03/24*	170	

Sources: compiled by WNISR, based on EDF REMIT-Data[205]

Notes: The expected duration is based on outage dates in use as of outage start, or within the few days after the reactor has been disconnected from the grid. For ongoing decennial visits, end of outage date is the date in use as of 1 November 2023, and can vary from the original date:

* Expected duration as of Outage start

** Revised date, as provided as of 1 November 2023

EDF expects these VD4 outages to last six months, much longer than the average of three to four months experienced through VD2 and VD3 outages. The Chief Technical Officer of EDF

203 - EDF, "4èmes Visites Décennales des Réacteurs du Palier 900 MW—Rapport annuel sur la mise en oeuvre des presriptions du 4ème réexamen périodique des réacteurs 900 MWe—2022", 2023.

204 - Bernard Doroszsuk, "Présentation du rapport annuel 2019 de l'Autorité de sûreté nucléaire (ASN) sur l'état de la sûreté nucléaire et de la radioprotection en France", President, Autorité de sûreté nucléaire/French Nuclear Safety Authority, Hearing before The Parliamentary Office for Scientific and Technological Assessment (OPECST), French Parliament, 28 May 2020 (in French), see http://videos.senat.fr/video.1628244_5ecf547f8a96f.audition-pleniere---autorite-de-surete-nucleaire?timecode=2963962, accessed 13 August 2020.

205 - EDF, "List of Outages", November 2023, see https://www.edf.fr/en/the-edf-group/who-we-are/activities/optimisation-and-trading/list-of-outages-and-messages/list-of-outages, accessed 2 November 2023.

Group and CEO of EDF R&D, Bernard Salha, told French Parliament in February 2023 that the work volume of a VD4 was five times larger than that of a VD3. He also said investments into the operating fleet have doubled over the past decade.[206]

As illustrated, many factors could lead to significantly longer outages. EDF has already started negotiating with ASN for the workload to be split in two packages, with the supposedly smaller second one to be postponed four years after the VD4.[207]

On 23 February 2021, the ASN issued detailed generic requirements for plant life extension.[208] The key aspects of ASN's decision were not the five short administrative articles but the two annexes setting the technical conditions and the timetable for work to be carried out. The challenge for operator EDF will be high, as ASN outlines:

> Over the coming five years, the nuclear sector will have to cope with a significant increase in the volume of work that is absolutely essential to ensuring the safety of the facilities in operation.
>
> Starting in 2021, four to five of EDF's 900 Megawatts electric (MWe) reactors will undergo major work as a result of their fourth ten-yearly outages. (...)
>
> All of this work will significantly increase the industrial workload of the sector, with particular attention required in certain segments that are under strain, such as mechanical and engineering, at both the licensees and the contractors.[209]

This was prior to the corrosion issues that struck EDF's fleet at the end of 2021. ASN has shown remarkable tolerance for extended timescales of refurbishments and upgrades in the past; many of the post-Fukushima measures have not yet been implemented eleven years after the events, for example. As of the end of 2020, none of the 56 French reactors were backfitted entirely according to ASN requests issued in 2012. According to some estimates, the completion of the work program could take until 2039.[210]

Additionally, the implementation of work to be carried out as part of the lifetime extension beyond 40 years stretches over 15 years until 2036, when the last 900 MW reactor is supposed to be upgraded: Chinon B-4, connected to the grid in 1987, gets the 15-year delay to implement 15 of a total of 37 measures. By then, the unit will have operated for 49 years. This is just one

206 - Bernard Salha, Oral Evidence before the Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST), 16 February 2023; see OPECST, "Comptes Rendus de l'Office Parlementaire d'Evaluation des Choix Scientifiques et Technologiques—Nouvelle organisation du contrôle et de la recherche en sûreté nucléaire et en radioprotection", Office Parlementaire d'Evaluation des Choix Scientifiques et Technologiques/Parliamentary Office for the Evaluation of Scientific and Technological Choices, French Parliament, 16 February 2023, see https://www.senat.fr/travaux-parlementaires/office-et-delegations/office-parlementaire-devaluation-des-choix-scientifiques-et-technologiques.html, accessed 14 November 2023.

207 - ASN, "Réexamen périodique associé aux quatrièmes visites décennales des réacteurs du palier 900 MWe", Autorité de Sûreté Nucléaire/French Nuclear Safety Authority, Presentation at a meeting of Commission locale d'information des grands équipements énergétiques du Tricastin/Local information committee on the major energy facilities at Tricastin (CLIGEET), 4 July 2018.

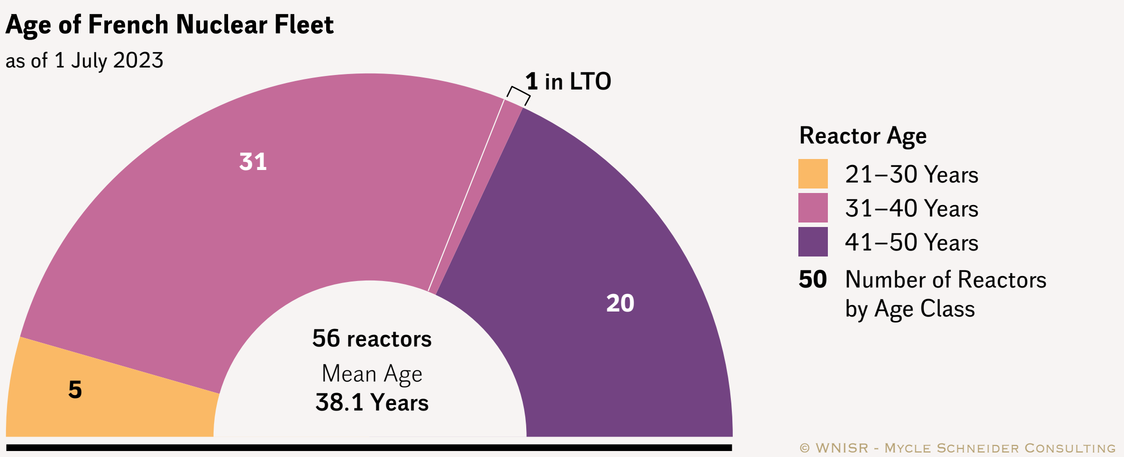
208 - ASN, "L'ASN prend position sur les conditions de la poursuite de fonctionnement des réacteurs de 900 MWe au-delà de 40 ans", Information Notice (in French), Autorité de Sûreté Nucléaire/French Nuclear Safety Authority, 25 February 2021, see https://www.asn.fr/Informer/Actualites/La-poursuite-de-fonctionnement-des-reacteurs-de-900-MWe-au-dela-de-40-ans, accessed 25 February 2021.

209 - ASN, "Abstracts ASN Report on the state of nuclear safety and radiation protection in France in 2020", Autorité de Sûreté Nucléaire/French Nuclear Safety Authority, 2021, see http://www.french-nuclear-safety.fr/Information/Publications/ASN-s-annual-reports/ASN-Report-on-the-state-of-nuclear-safety-and-radiation-protection-in-France-in-2020, accessed 27 July 2021.

210 - Manon Besnard and Yves Marignac, "Les mesures de renforcement du parc nucléaire français, dix ans après Fukushima", Institut négaWatt, 5 March 2021 (in French), see https://cdn.greenpeace.fr/site/uploads/2021/03/Institut-n%C3%A9gaWatt-Les-mesures-de-renforcement-du-parc-nucl%C3%A9aire-fran%C3%A7ais-10-ans-apr%C3%A8s-Fukushima-rapport-mars-2021-1.pdf, accessed 30 August 2022.

example, and it is the newest of the operating 900 MW reactor. ASN has accepted similar timescales for all 32 of the 900 MW units. The French Nuclear Safety Authorities have proven flexible, and—considering the dire state of the reactor fleet—pressure for even more flexibility might increase in the future, particularly in the winter 2022–2023.

Figure 37 • Age Distribution of French Nuclear Fleet (by Decade)



Sources: WNISR, with IAEA-PRIS, 2023

Financial Trouble

Operating costs have increased substantially over the past few years (see also previous WNISR editions). The Court of Accounts calculated the operating costs for the year 2019 at €43.8/MWh ($US\$_{2019}$49/MWh) when using an "accounting" methodology and €64.8/MWh ($US\$_{2019}$72.6/MWh) when applying an "economic" approach (taking into account past investments) as chosen by the Court. Lifetime extension from 40 to 50 years would cost over $€_{2015}$35 /MWh [$€_{2022}$39/MWh or $US\$_{2022}$41/MWh] based on EDF figures", without considering the effect on post-operational costs.[211] Whatever the uncertainties of the respective cost estimates, there is no doubt that the additional costs for refurbishment and upgrades in view of lifetime extensions remain far below any cost estimate for newbuild.

The Energy Regulatory Commission recalculated the electricity generating costs of the French nuclear fleet (incl. the Flamanville-3 EPR) for the years 2026–2030 in the range of $€_{2022}$53.8–60.7/MWh ($US\$_{2022}$56.6–63.9/MWh) depending on the definition of the scope.[212]

Outages that systematically exceed planned timeframes are particularly costly. EDF's net financial debt increased by about €10 billion ($US\$_{2023}$10.6 billion) over the period 2019–2021 to

211 - Cour des Comptes, "L'analyse des coûts du système de production électrique en France—Observations Définitives", S2021-2052, French Court of Accounts, deliberated 15 September 2021, published 13 December 2021 (in French), see https://www.ccomptes.fr/fr/publications/lanalyse-des-couts-du-systeme-electrique-en-france, accessed 14 November 2023.

212 - CRE, "Coût de production du parc nucléaire existant d'EDF", Commission de Régulation de l'Énergie/Energy Regulatory Commission, 27 July 2023.

a total of €43 billion (US$$_{2021}$51 billion)—as of the end of 2021.[213] In 2022 alone, net debt jumped by €21.5 billion (US$$_{2022}$22.6 billion) to €64.5 billion (US$$_{2022}$67.9 billion) at the end of the year. In the first half of 2023, the debt load rose to €64.8 billion (US$$_{2023}$70 billion).[214] Luc Rémont, EDF's incoming CEO, stated during a hearing at the Finance Commission of the National Assembly:

> We are on the eve of an industrial challenge which, in reality, is out of all proportion with the Group's history for several reasons. The first is that we are beginning this steep path towards greater investment in electrification with the somewhat heavy rucksack of a 65 billion euro debt which is—I'm sure, even for the Finance Commission, 65 billion euros is a significant amount—I can assure you for a company, it is the heaviest amount a company can experience in Europe and so, naturally, it is part of the elements that define our capacities and the ways in which we can envisage this new investment cycle.[215]

Rémont added that the Group never before had to invest on the order of €25 billion per year (US$_{2023}$$27 billion/year) of which 80 percent in France while "debt can hardly increase more".[216]

EDF had been losing 100,000–200,000 clients *per month* for several years. However, as the sky-rocketing price increases continued into 2022, some consumers returned to EDF's regulated tariffs that profited from the government-imposed price control mechanism. EDF claims an increase of about half a million clients between September 2021 and May 2022[217], a further half a million until the end of 2022, and 400,000 until mid-2023.[218] The drawback was that during low nuclear production and excessively high prices on the market, this forced EDF to "buy volumes [of power] at a price that is higher than we [EDF] resell it to the clients at the regulated tariff", an EDF executive director stated.[219]

213 - EDF, "Consolidated Financial Statements at 31 December 2021", 13 April 2021, see https://www.edf.fr/sites/groupe/files/2022-02/annual-results-2021-consolidated-financial-statements-20220218.pdf, accessed 4 July 2021.

214 - EDF, "Consolidated Financial Statements at 31 December 2022", February 2023, see https://www.edf.fr/sites/groupe/files/2023-02/annual-results-2021-consolidated-financial-statements-2023-02-17.pdf; and

215 - Luc Rémont, oral evidence to the Finance Commission of the National Assembly, 19 July 2023.

216 - Ibidem.

217 - Sharon Wajsbrot, "La crise de l'énergie permet à EDF d'engranger de nouveaux clients", *Les Echos*, 29 June 2022 (in French), see https://www.lesechos.fr/industrie-services/energie-environnement/edf-profite-de-la-crise-de-lenergie-pour-engranger-de-nouveaux-clients-1582529, accessed 29 June 2022.

218 - EDF, "2023 Half-Year Results", Press Release, 27 July 2023, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/2023-half-year-results-substantially-higher-ebitda-and-stabilisation-of-net-financial-debt-gradual-return-to-better-nuclear-fleet-availability-good-overall-operational-performance, accessed 4 September 2023.

219 - Sharon Wajsbrot, "La crise de l'énergie permet à EDF d'engranger de nouveaux clients", *Les Echos*, 29 June 2022, op.cit.

The Flamanville-3 EPR Saga Continued

"The EPR is an overly complicated, virtually unbuildable machine..."

Henry Proglio, Honorary Chairman, EDF[220]

The 2005 construction decision of Flamanville-3 (FL3) was mainly motivated by the industry's attempt to confront the serious problem of maintaining nuclear competence. Fifteen years later, the regulator ASN still drew attention to the "need to reinforce skills, professional rigorousness and quality within the nuclear sector."[221]

In December 2007, Electricité de France (EDF) started construction on FL3 with a scheduled startup date of 2012. The project has been plagued with design issues and quality-control problems, including basic concrete and welding difficulties similar to those at the Olkiluoto (OL3) project in Finland, which started construction two-and-a-half years earlier. (See earlier WNISR editions.) These problems never stopped.

In March 2020, EDF had stated that fuel loading would be delayed to "late 2022" and construction costs re-evaluated at €12.4$_{2015}$ billion (US\$$_{2015}$13.8 billion), an increase of €1.5$_{2015}$ billion (US\$$_{2015}$1.7 billion) over the previous estimate.[222] In addition to the overnight construction costs, as of December 2019, EDF indicated more than €4.2 billion (US\$$_{2019}$4.7 billion) was needed for various cost items, including €3 billion (US\$$_{2019}$3.4 billion) of financial costs.

In January 2022, EDF estimated the overnight costs at €$_{2015}$12.7 billion (US\$$_{2015}$14.1 billion).[223] In December 2022, the figure was updated to €$_{2015}$13.2 billion (US\$$_{2015}$14.6 billion).[224] In 2020, the French Court of Audits estimated the total cost, including financing and other associated costs, at €$_{2015}$19.1 billion (US\$$_{2015}$21 billion).[225] The Court estimated that the cost of electricity from FL-3 would be €$_{2015}$110–120/MWh (US\$$_{2015}$122–133/MWh). This estimate has not been publicly updated.

The fuel issue that struck the Taishan EPRs and kept Unit 1 off-grid for over one year had consequences for FL3. EDF decided to refabricate 64 of the 241 fuel assemblies that had already been produced. These were approved by ASN and delivered to the site.

220 - Henri Proglio, Testimony before the Enquiry Committee Hearing, French National Assembly, 13 December 2022; see Commission d'Enquête visant à établir les raisons de la perte de souveraineté et d'indépendance énergétique de la France, "Rapport d'enquête n°1028—Tome 2 - 16e législature", Enquiry Commission to establish the reasons for France's loss of energy sovereignty and independence, Assemblée Nationale/French National Assembly, filed 30 March 2023 (in French), see https://www.assemblee-nationale.fr/dyn/16/rapports/ceindener/l16b1028-t2_rapport-enquete, accessed 3 November 2023.

221 - ASN, "ASN Report on the state of nuclear safety and radiation protection in France in 2020—Abstracts", Autorité de Sûreté Nucléaire/French Nuclear Safety Authority, 2021, see https://www.french-nuclear-safety.fr/content/download/178655/file/Abstracts-of-the-full-ASN-Report-on-the-State-of-nuclear-safety-and-radiation-protection-in-France-in-2020.pdf, accessed 30 August 2022.

222 - EDF, "Annual Financial Report 2019—Universal Registration Document—New version of the Reference Document", Electricité de France, original version filed 13 March 2020, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/regulated-information/reference-document/edf-urd-annual-financial-report-2019-en.pdf, accessed 14 November 2023.

223 - EDF, "Update on the Flamanville EPR", Press Release, Electricité de France, 12 January 2022, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/update-on-the-flamanville-epr, accessed 31 August 2022.

224 - EDF, "Universal Registration Document 2022 Including the Annual Financial Report", Electricité de France, original document in French filed 21 March 2023, see https://www.edf.fr/en/the-edf-group/dedicated-sections/investors/regulated-information, accessed 3 November 2023.

225 - Court of Accounts, "La filière EPR", Cour des Comptes, 9 July 2020. See WNISR2020 for excerpts from the report.

As of mid-2023, the latest projected date for fuel loading is the first quarter 2024. Because of a fabrication default (see earlier WNISR editions), the vessel head will have to be replaced at the end of the first refueling cycle scheduled for the second half of 2025."[226]

Conclusion

The French nuclear industry remains under a high level of stress. The full re-nationalization of EDF, analysts agree, will not solve its structural problems: an ageing nuclear fleet with lowest performance in decades, manpower and competence challenges, unprecedented investment needs at times of unprecedented net debt, and never-ending problems at the only active construction site at Flamanville.

Not covered here, but to this list should be added serious fuel chain issues, climate impact, social movements, and some unexpected opposition. Especially the plutonium-economy part of the industry is experiencing its own crisis with historically low throughput at the spent fuel reprocessing plant at La Hague and at the uranium-plutonium mixed-oxide (MOX) fuel fabrication facility MELOX at Marcoule. Consequently, spent fuel pools are filling up and the stocks of unirradiated plutonium have increased to unprecedented levels.

Confronted with this avalanche of problems, the French government has chosen to insist on the launch of a nuclear newbuild program—supported by a majority in the National Assembly. And EDF follows suit:

> On 29 June 2023, EDF announced that it was making the applications for approval to launch construction of the first pair of EPR 2 reactors at Penly, and starting other administrative procedures required for their completion and connection to the electricity transmission network. EDF's objective is to begin preparatory work in mid-2024.[227]

The EPR2 does not even exist on paper. It increasingly looks as if the current administration and nuclear establishment have not learned the lessons of the Flamanville EPR1 disaster, as spelled out in the chapter headlines of a 2019-assessment commissioned by EDF's President: "An unrealistic initial [cost] estimate; (...) An inappropriate project governance; Struggling project teams; (...) Insufficiently advanced studies at launch; (...) Generalized loss of competence."[228]

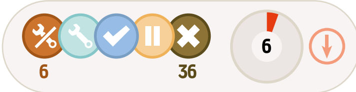
Largely unreported, the science community in France is far from offering unanimous support of the newbuild initiative. As of the end of October 2023, close to 1,200 scientists had signed the aforementioned "Call by scientists against a new nuclear program".

226 - EDF, "2023 Half-Year Results", Press Release, 27 July 2023, op.cit.

227 - EDF, "Half-Year Financial Report at 30 June 2023", Electricité de France, 27 July 2023, see https://www.edf.fr/sites/groupe/files/2023-07/2023-07-27-half-year-results-financial-report.pdf, accessed 5 November 2023.

228 - Jean-Martin Folz, "La construction de l'EPR de Flamanville – Rapport au Président Directeur Général d'EDF", commissioned by EDF in July 2019, Ministry of Economy and Finances, delivered 25 October 2019, see https://www.vie-publique.fr/rapport/271429-la-construction-de-lepr-de-flamanville, accessed 5 November 2023.

GERMANY FOCUS



Nuclear Power in Germany – The Last 25 Years in a Nutshell

Since the beginnings of commercial nuclear operations, there has always been substantial opposition towards the technology in Germany. Protests in the 1970s (Wyhl, Brokdorf, Gorleben, and others) with up to 100,000 participants led to the formation of a politically strong anti-nuclear movement that culminated in the formation of the Green Party.[229] The 1998-election led to the formation of the first "Red-Green" government, a coalition made up of the Social Democrats (SPD) and the Green Party, led by Chancellor Gerhard Schröder. The ensuing first Renewable Energy Act ("Erneuerbare Energien Gesetz" or EEG)[230] laid the groundwork for Germany's renewable energy expansion, and the so-called "consensus agreement" ("Atomkonsens"), that limited operational lifetimes of German nuclear power plants to a maximum of 32 years, and, most notably, involved no financial compensation for utilities.[231] It was molded into legislation in 2002. In 2010, a conservative-liberal, pro-business, and pro-nuclear Government, consisting of the Christian Democrats (CDU & CSU) and the Liberal Democratic Party (FDP), led by physicist Chancellor Angela Merkel, passed legislation that extended the lifetimes of nuclear power plants completed before 1981 by eight years and all other plants' lifetimes by 14 years.[232] However, immediately after the 2011-Fukushima disaster, the same Government implemented a three-month operational moratorium for seven reactors built before 1980 and temporarily suspended the above-mentioned lifetime extensions for all other plants.[233]

The Ethics Commission for a Safe Energy Supply, instated by Chancellor Merkel, came to the conclusion:

> The Ethics Commission is strongly convinced that the withdrawal from nuclear energy can be completed within one decade using the measures presented here for the energy transition. Society should commit to this objective and the necessary measures. It is only by having a clear, scheduled objective as a basis that the necessary decisions on planning and investment can be taken. (...)

229 - *Deutschlandfunk*, "Eine Chronik der Anti-Atomkraft-Bewegung", 14 April 2023 (in German), see https://www.deutschlandfunk.de/anti-atomkraft-bewegung-deutschland-chronik-100.html, accessed 31 July 2023.

230 - German Federal Government, "Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz) sowie zur änderung des Energiewirtschaftsgesetzes und des Mineralölsteuergesetzes", enacted 29 March 2000, promulgated 30 March 2000 (in German), see https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl100s0305.pdf#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl100s0305.pdf%27%5D__1690794026102, accessed 31 July 2023.

231 - German Federal Government, VEBA AG, VIAG AG et al.,, "Vereinbarung zwischen der Bundesregierung und den Energieversorgungsunternehmen vom 14. Juni 2000", signed 11 June 2001 (in German), June 2000, see https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Nukleare_Sicherheit/atomkonsens.pdf, accessed 31 July 2023.

232 - German Bundestag, "Entwurf eines Elften Gesetzes zur Änderung des Atomgesetzes", Drucksache 17/3051 (in German), Deutscher Bundestag, 28 September 2010, see https://dserver.bundestag.de/btd/17/030/1703051.pdf, accessed 31 July 2023 and German Bundestag, "Vorgang – Gesetzgebung— Elftes Gesetz zur Änderung des Atomgesetzes", 2010 (in German), see https://dip.bundestag.de/vorgang/elftes-gesetz-zur-%C3%A4nderung-des-atomgesetzes/29435, accessed 5 November 2023.

233 - Mario Kendziorski, Claudia Kemfert et al., "Nuclear Turn: Closing Down Nuclear Power Plants Opens up Prospects for the Final Repository Site Search", *DIW Weekly Report*, No.47, 2021, see http://www.diw.de/sixcms/detail.php?id=diw_01.c.830332.de, accessed 31 July 2023.

> The withdrawal from nuclear energy is necessary and is recommended to rule out future risks that arise from nuclear in Germany. It is possible because there are less risky alternatives.[234]

The closure of eight of Germany's oldest[235] reactors and the progressive phaseout of the remaining nine by the end of 2022 was drafted into legislation, effectively reactivating the former "consensus agreement" (see Table 8 for the phaseout schedule). With no political party dissenting, it looked virtually irreversible under any political constellation. On 6 June 2011, only one week after the Ethics Commission submitted its report, the German Bundestag passed a seven-part energy transition legislation almost by consensus that came into force on 6 August 2011 (see earlier WNISR editions for details).[236] This renewed phaseout scheme prompted the utilities to sue for compensation that, after ten years of legal battles in German courts of law and international arbitrations courts, led to the payment of a total of €2.4 billion (US$$_{2021}$2.8 billion) in 2021.[237]

In September 2021, legislative elections saw the SPD become the largest political party in Germany. But even in a coalition with the Green Party they would not have had a parliamentary majority, so after complex negotiations, an unprecedented "traffic light" ("Ampel") coalition-government was formed by adding the FDP (yellow) to the SPD (red) and Greens.

One year into the legislative period, on 5 September 2022, Green party member Robert Habeck, Minister for the Economy and Climate Protection and Vice-Chancellor of Germany, presented the results of a second stress test of the electricity system's resilience for the winter 2022–2023. He announced that he would recommend to the Government to transfer two of the three remaining operating nuclear reactors, namely Isar-2, and Neckarwestheim-2 into "reserve status" as of the end of 2022. Emsland would be shut down as planned by 31 December 2022.[238] This left the FDP, that had over the course of 2022 taken over a role as nuclear advocacy party, dissatisfied, prompting infighting within the coalition, mainly between Finance Minister and FDP leader Christian Lindner, and Robert Habeck. On 17 October 2022, Chancellor Olaf Scholz ended the dispute by announcing in an executive order that all three nuclear power plants would remain operational until 15 April 2023. The order also determined that no new fuel assemblies would be acquired.[239] The reactors would merely operate in "stretch mode", exhausting the fuel in the core. The required change of the Atomic Energy Act was adopted

234 - Ethics Commission for a Safe Energy Supply, "Germany's energy transition – A collective project for the future", 30 May 2011, on behalf of Federal Chancellor Dr. Angela Merkel, see https://www.bundesregierung.de/resource/blob/2065474/457334/bae4db36ddee0379dac83f1a14cab337/2011-05-30-abschlussbericht-ethikkommission-en-data.pdf, accessed 3 August 2023.

235 - Including the Krümmel and Brunsbüttel reactors that by then had not generated power for almost two and four years respectively.

236 - *DIW Weekly Report*, "Nuclear Turn: Closing Down Nuclear Power Plants Opens up Prospects for the Final Repository Site Search", 2021, op. cit.

237 - €1.425 billion (US$$_{2021}$1.7 billion) to Vattenfall, €880 million (US$$_{2021}$1 billion) to RWE, €80 million (US$$_{2021}$95 million) to EnBW, and €42,5 million (US$$_{2021}$50 million) to E.ON; see Jürgen Flauger and Silke Kersting, "Entschädigung für Atomausstieg: Konzerne erhalten 2,4 Milliarden Euro", *Handelsblatt*, 5 March 2021 (in German), see https://www.handelsblatt.com/unternehmen/energie/energiewirtschaft-entschaedigung-fuer-atomausstieg-konzerne-erhalten-2-4-milliarden-euro/26977850.html, accessed 31 July 2023.

238 - BMWK, "Power system stress test: Federal Ministry for Economic Affairs and Climate Action stepping up precautionary measures to safeguard power grid stability this winter", Press Release, Bundesministerium für Wirtschaft und Klimaschutz/Federal Ministry for Economic Affairs and Climate Action, Federal Government of Germany, 5 September 2022, see https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/09/20220905-power-system-stress-test.html, accessed 28 July 2023.

239 - Nikolaus Kurmayer, "German nuclear scuffle: Scholz cracks down, insists on keeping all plants", *Euractiv*, 17 October 2022, see https://www.euractiv.com/section/energy/news/german-nuclear-scuffle-scholz-cracks-down-insists-on-keeping-all-plants/, accessed 28 July 2023.

by the cabinet a few days later, and by the Bundestag in November 2022. On 15 April 2023, all three plants were closed.[240]

Sky-rocketing energy prices in late 2021, the war in Ukraine, and high German dependency on Russian fossil fuel imports (gas, oil, and coal) provided a further opportunity for some pro-nuclear voices in the country to receive considerable attention. In fact, the discourse of the "German isolated phaseout decision in a world going all nuclear" had entered the main media already in the past few years.

An Unexpected Debate Over Potential Lifetime Extensions

The war in Ukraine triggered a public controversy that hardly assessed options based on factual understanding of their respective implications but often consisted of a fact-free opinion debate. Are you for or against lifetime expansions? Never mind legal aspects, technical feasibility, costs, and potential safety implications. A whole series of opinion polls showed comfortable majorities in favor of stretching the operation of the three remaining reactors by a few months or even up to five years. The public perception linked continued operation of the reactors to the hope for more independence from Russian gas.[241] A mirage, as reports commissioned in the spring of 2023 showed after the dreaded winter had been overcome without the severe blackouts that had been predicted by some:[242] the lifetime "stretching" had close to no effect on security of supply, and impact on wholesale electricity prices in 2022 and 2023 was limited to under 1 percent.[243] Instead, mild temperatures in winter and active reduction of consumption by consumers had reduced German gas demand in 2022 by 14 percent compared to the previous four-year average.[244]

On 7 March 2022, three days after the Russian army attacked and then occupied the Zaporizhzhia nuclear power plant, the German Government issued a 5-page joint statement of the Ministries of Environment and Economy assessing a potential restart of the three reactors

240 - Laura Paddison, Nadine Schmidt and Inke Kappeler, "'A new era': Germany quits nuclear power, closing its final three plants", *CNN*, 15 April 2023, see https://edition.cnn.com/2023/04/15/europe/germany-nuclear-phase-out-climate-intl/index.html, accessed 28 July 2023.

241 - Some surveys link the question directly to gas shortages, without any indication of the very low impact the continued use of nuclear power would have on gas consumption (<1 percent), e.g. Infratest for *ARD DeutschlandTrend*, see *Tagesschau*, "Mehrheit für längere AKW-Laufzeiten", *ARD Deutschlandtrend* (in German), 24 June 2022, see https://www.tagesschau.de/inland/deutschlandtrend/deutschlandtrend-3051.html, accessed 28 July 2023.

242 - Nikolaus Doll, "„Müssen davon ausgehen, dass es im Winter Blackouts geben wird"", *Welt am Sonntag*, 19 November 2022 (in German), see https://www.welt.de/politik/deutschland/plus242204899/Katastrophenschutz-Davon-ausgehen-dass-es-im-Winter-Blackouts-geben-wird.html; and *The Associated Press* and *dpa*, "Wird die Blackout-Gefahr real? Eindringliche Warnungen aus Berlin und Paris", as published on *euronews* (in German), 6 October 2022, see https://de.euronews.com/2022/10/06/wird-die-blackout-gefahr-real-eindringliche-warnungen-aus-berlin-und-paris; both accessed 31 July 2023.

243 - Tim Höfer and Alexander Brinkmann, "Effekte der Laufzeitverlängerung der deutschen Kernkraftwerke", Analysis Paper (in German), commissioned by Green Planet Energy and Greenpeace, enervis energy advisors, 14 April 2023, see https://green-planet-energy.de/fileadmin/images/presse/GPE_Effekte_der_AKW-Laufzeitverl%C3%A4ngerung.pdf; and Felix Hackenbruch, "Stromüberschüsse im Winter: War der AKW-Streckbetrieb unnötig?", *Tagesspiegel*, 4 June 2023 (in German), see https://www.tagesspiegel.de/politik/stromuberschusse-im-winter-war-der-akw-streckbetrieb-unnotig-9615218.html; both accessed 28 July 2023.

244 - *Tagesschau*, "Gasverbrauch deutlich gesunken", 6 January 2023 (in German), see https://www.tagesschau.de/wirtschaft/verbraucher/gasverbrauch-deutschland-101.html, accessed 28 July 2023.

that were closed at the end of 2021 and the potential lifetime extension of the remaining three operating reactors beyond the legal closure date of end of 2022:[245]

- The restart of the three units closed end of 2021 is "out of the question" notably due to the expired operating license.
- The lifetime extension of the still operating units would not lead to additional power generation in the winter 2022/2023, as there is no new fuel available before fall 2023 at the earliest.[246]
- A lifetime extension of the currently still operating three units beyond the end of 2022 would require an in-depth safety assessment of each of the reactors last carried out in 2009. The outcome and potential backfitting and upgrading work needed cannot be reliably predicted.
- A lifetime extension could not be economically justified for 2–3 years and would not make sense under 3–5 years considering the safety related issues and the need to re-train staff. The two ministries consider that in that timeframe there are other options.
- From a constitutional rights perspective, a lifetime extension would require a comprehensive, new risk-benefit assessment by the legislator. "Against this background, the expected lawsuits against a possible lifetime extension would definitely have promising chances of success."
- The operators have signaled that a lifetime extension would essentially mean the takeover of legal and economic risks by the state. As the two ministries consider that compromising on safety is not an option, lifetime extension could mean lengthy backfitting programs in the period 2022–2024.
- In conclusion, the two ministries "cannot recommend a lifetime extension of the three still operating nuclear power plants".

Four days after the government statement and two weeks after Russia had launched its all-out war against Ukraine, the parliamentary group of the far-right AfD (Alternative für Deutschland/Alternative for Germany) tabled a proposal for a resolution in which the German Bundestag would "call on the Federal Government to implement, together with the Länder Governments a lifetime extension of the nuclear power plants" and "immediately give nuclear power plant operators unambiguous and binding assurances that the nuclear power plants may be operated without restriction until their technically reasonable end of life."[247] The proposal was rejected by all of the parliamentary committees and, on 7 July 2022, received a unanimous

245 - BMWK and BMUV, "Prüfung des Weiterbetriebs von Atomkraftwerken aufgrund des Ukraine-Krieges", Bundesministerium für Wirtschaft und Klimaschutz/Federal Ministry for Economic Affairs and Climate Action and Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz/Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (in German), 7 March 2022, see https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Nukleare_Sicherheit/laufzeitverlaengerung_akw_bf.pdf, accessed 28 July 2023.

246 - It has been argued that the reactors could go into "stretch operation" (Streckbetrieb), lowering generation in the summer and saving fuel for the winter beyond the end of the year. However, that would mean additional quantities of other fuel, notably gas, would have to be burnt in the summer to make up for the saved nuclear kilowatt-hours. That would not change the overall availability of non-Russian fuel in the winter 2022/2023. Also, utility representatives have stated it would rather take between one and two years to get new fuel manufactured.

247 - AFD Parliamentary Group, "Keine Abschaltung von Kernkraftwerken – Erst recht nicht in einer neuen Realität", Drucksache 20/1021 (in German), Motion introduced to the German Bundestag, 15 March 2022, see https://dserver.bundestag.de/btd/20/010/2001021.pdf, accessed 28 July 2023.

rejection by all parliamentary groups from the far left to the Christian Democrats. The vote ended 581 to 67, whereas only AfD members and one independent voted for the proposal.[248]

In June 2022, all three operators of the remaining plants, EnBW, E.ON, and RWE, opposed lifetime extensions citing technical and regulatory challenges that would have to be overcome.[249]

Over the summer of 2022, noteworthy developments included the following:

- A legal analysis commissioned by Greenpeace concluded on 22 July 2022 that any form of operation of the remaining reactors beyond the end of the year would violate constitutional law, necessitate significant backfitting, and require cross-border consultations under E.U.-Environmental Impact Assessment legislation and ESPOO Convention.[250]
- On 26 July 2022, the smallest government coalition partner FDP called for a lifetime extension of all three reactors to 2024, arguing: "This is the period when we face energy shortages. That is why we must be prepared for it."[251]
- On 28 July 2022, five key SPD parliamentarians on energy and climate issues, led by the parliamentary group's Vice-President Matthias Miersch, sent a 4-page letter to party members pointing to a comprehensive list of issues highlighting problems around the potential lifetime extension, like the "challenges in times of gas shortages are in the industry and the provision of heat – not in the power sector"; while less suitable than gas plants, coal plants are more suitable to make up for shortages than nuclear plants, as they were more flexible; under regular circumstances, the three nuclear plants would have had to undergo a comprehensive decennial safety inspection in 2019, which they were exempted from considering the anticipated closure in 2022—that safety review would be "mandatory", could last several years and entail "significant investment needs"; the operators do not want to bear the legal, economic, and safety risks, that would have to be covered by the state.[252]
- Early September 2022, a draft motion for the regular Green Party congress scheduled for October 2022 was circulated and called on the federal party executive board, the parliamentary group, and the federal government "to stick to the 31 December 2022 phaseout date for the last three nuclear power plants in Germany."[253]

248 - Deutscher Bundestag, "Parlament—Namentliche Abstimmung—07.07.2022: Bereithaltung von Ersatzkraftwerken (Beschlussempfehlung)", German Bundestag, 7 July 2022 (in German), see https://www.bundestag.de/parlament/plenum/abstimmung/abstimmung?id=793, accessed 28 July 2023.

249 - *WDR*, "Atomkraftwerk-Betreiber erteilen Laufzeitverlängerung Absage", *Westdeutscher Rundfunk*, 21 June 2022 (in German), see https://www1.wdr.de/nachrichten/atom-kraft-laufzeit-verlaengerung-100.html, accessed 28 July 2023.

250 - Ulrich Wollenteit, "Stellungnahme zu der von der TÜV SÜD Industrie Service GmbH erstellten und auf der Seite des Staatsministeriums für Umwelt und Verbraucherschutz des Freistaat Bayern veröffentlichten 'Bewertung der konkreten erforderlichen technischen Maßnahmen für einen Weiterbetrieb des KKI 2 bzw. eine Wiederinbetriebnahme des Blocks C des KRB II'", Legal Opinion (in German), commissioned by Greenpeace, Rechtsanwälte Günther 22 July 2022, see https://www.greenpeace.de/publikationen/20220729-greenpeace-stellungnahme-guenther-akw-laufzeitverlaengerung.pdf, accessed 28 July 2023.

251 - Eva Ellermann, "Atomkraftwerke sollen bis 2024 laufen", *Tagesschau*, *ARD Berlin* (in German),, 26 July 2022, see https://www.tagesschau.de/inland/fpd-atomkraftwerke-laufzeit-energiekrise-gas-ukraine-101.html, accessed 25 May 2023.

252 - Matthias Miersch et al. Letter to SPD party members, 28 July 2022.

253 - Markus Decker, "Atomkraft: Grüne Basis will Laufzeitverlängerung stoppen", *RND / RedaktionsNetzwerk Deutschland* (in German), 1 September 2022, see https://www.rnd.de/politik/atomkraft-gruene-basis-will-laufzeitverlaengerung-stoppen-GSAXELPJ2ZB7LNSWNAUA7JUI2Y.html, accessed 11 September 2022.

Between mid-July and early September 2022, the four grid operators in Germany carried out a second stress test on security of supply and stability of the grid for the winter 2022/2023 under significantly more stringent assumptions. The hour-by-hour analysis included the potential contributions or needs of neighboring countries. A sensitivity analysis found the greatest potential impact with the performance of the French nuclear fleet and the water levels of rivers in Germany (in particular for the shipment capacity of coal).

The French Government had assured the German Government, "orally and in writing", so said Minister Habeck on 5 September 2022, that 50 GW of the installed total of 61 GW of French nuclear capacity would be operational in the winter.[254] The French assurances for winter 2022/2023 had seemed to be based on highly optimistic assumptions, and the German grid operators consequentially judged it necessary to model scenarios with a French nuclear capacity limited to 45 GW and 40 GW respectively.[255] The most challenging scenario combined the limited nuclear capacity with the assumption of unavailability of half of the reserve capacity (mainly coal) and half of the gas plants in southern Germany.[256]

Minister Habeck concluded from the stress test results that "it remains highly unlikely that we will face a crisis or an extreme scenario", but due to the cumulation of circumstances, "given all these risks, we cannot rely on our neighboring countries to have enough power stations available to help stabilize our power grid at short notice in the event of grid congestion."[257] Therefore, the ministry decided to propose the creation of a new reserve capacity, limited in time, in the form of the two southern nuclear plants Isar-2 and Neckarwestheim-2. The two reactors should "remain available until mid-April 2023 so that they can, if necessary, make an additional contribution to the power grid in southern Germany this winter."[258]

Other countermeasures recommended by the grid operators were implemented, including additional production in biogas plants and the increase of transmission capacity and effectiveness. The ministry clarified that the two nuclear units should be "deployed only when it seems likely that the other instruments will be insufficient to avert a supply crisis." The extension beyond mid-April 2023 or the reactivation in the winter 2023/2024 "is not possible due to the safety status of the nuclear power plants and the fundamental considerations about the risks of nuclear power." [259]

The idea was to monitor European capacity availability throughout the winter and, should it have appeared in November or early December 2022 that a severe shortage was to emerge in

254 - Oral statement during press conference, see also BMWK, "FAQ Liste Zweiter Stresstest und Maßnahmen zur Sicherung der Stromnetz-Stabilität im Winter 22/23", Bundesministerium für Wirtschaft und Klimaschutz/Federal Ministry for Economic Affairs and Climate Action (in German), September 2022, see https://www.bmwk.de/Redaktion/DE/Downloads/F/faq-zweiter-stresstest-massnahmen-sicherung-stromnetz-stabilitat.pdf?__blob=publicationFile&v=8, accessed 28 July 2023.

255 - 50Hertz, amprion, Tennet and Transnet BW, "Sonderanalysen Winter 2022/2023 - Ergebnisse & Empfehlungen", 5 September 2022 (in German), see https://www.netztransparenz.de/portals/1/20220905_Sonderanalysen%20Winter%2020222023%20%e2%80%93%20Ergebnisse%20und%20Empfehlungen.pdf, accessed 28 July 2023.

256 - BMWK, "FAQ Liste Zweiter Stresstest und Maßnahmen zur Sicherung der Stromnetz-Stabilität im Winter 22/23", September 2022, op. cit.

257 - BMWK, "Power System Stress Test: Federal Ministry for Economic Affairs and Climate Action Stepping up Precautionary Measures to Safeguard Power Grid Stability This Winter", Press Release, Bundesministerium für Wirtschaft und Klimaschutz/Federal Ministry for Economic Affairs and Climate Action, Federal Government of Germany, 5 September 2022, see https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/09/20220905-power-system-stress-test.html, accessed 28 July 2023.

258 - BMWK, "Power System Stress Test: Federal Ministry for Economic Affairs and Climate Action Stepping up Precautionary Measures to Safeguard Power Grid Stability This Winter", September 2022, op. cit.

259 - Ibidem.

January 2023—e.g. due to lower than expected French nuclear capacity—the two southern reactors would keep operating until their fuel exhausted. Otherwise, the units would have been shut down at year-end as stipulated under the current legislation and restarted only should a crisis situation have occurred later in the winter. This would not have been a stop-and-go kind of operation, but once restarted, the reactors would have kept operating until fuel exhaustion.

Meanwhile, the French government, faced with an unprecedented unavailability level of its own nuclear power fleet, called on Germany, in the name of mutual solidarity, to extend the operation of the three remaining reactors "for a few months", while assuring to upgrade the gas links to Germany in return.[260] In 2022, French nuclear production fell to the lowest levels since 1988 due to extended, unplanned outages that kept up to two thirds of the French fleet-capacity down, resulting in neighboring countries having to export large quantities of power to France which, for the first time since 1980, turned into a net power importer over the year. Germany has been a net power exporter to France for many years, especially in winter. In 2022, annual net export reached 15 TWh. (See France Focus).

Following the publication of the stress test results and the conclusions of the Ministry of Economy and Climate Protection, coalition member FDP reiterated the call for a lifetime extension at least until 2024, making a 180 degree turn from statements of the year before when party leader Lindner had said that nuclear power "may be CO_2-free, but certainly not sustainable".[261] The party leader of the Christian Democrats (CDU), Friedrich Merz, called the potential closure of the three reactors at year end "completely absurd".[262] Other conservative politicians even called for nuclear newbuild in Germany. Former Federal Transport Minister Andreas Scheuer of Bavarian CDU-equivalent CSU stated: "My formula is 3+3+3: Three nuclear plants must continue operation, three must be reactivated and three new plants must be built".[263]

The political feud between Greens and FDP escalated when Lindner refused to accept the proposition once it was brought before cabinet on 11 October 2022 and advocated for the continued operation of all three reactors instead. Meanwhile, on 14 October 2022, the Green party conference approved Habeck's plans for stretch-operation until 15 April 2023 but explicitly opposed the procurement of new nuclear fuel, which would be required for continued operation until 2024, as proposed by the FDP and conservatives.[264]

In an attempt to mediate between Greens and FDP, several talks were held at Chancellor Scholz's office. As these talks had led to no conclusions, in the late afternoon of 17 October 2022, Chancellor Scholz issued an executive order, ending the dispute between the two junior

260 - Sharon Wajsbrot, "Un « deal » franco-allemand et un appel à la sobriété pour éviter la panne de courant", *Les Echos*, 6 September 2022 (in French), see https://www.lesechos.fr/industrie-services/energie-environnement/un-deal-franco-allemand-et-un-appel-a-la-sobriete-pour-eviter-la-panne-de-courant-1785896, accessed 26 May 2023.

261 - Jasmin Kalarickal, "Die FDP argumentiert unterkomplex", *taz* (in German), 6 September 2022, see https://taz.de/Streit-ueber-AKW-Laufzeitverlaengerung/!5876450/, accessed 28 July 2023.

262 - *ZDF* and *AFP*, "Kernkraftwerke: FDP und CDU wollen dauerhaften Weiterbetrieb", *ZDF* (in German), 6 September 2022, see https://www.zdf.de/uri/532a315e-d1f6-4c43-8cea-7357c1029527, accessed 11 September 2022.

263 - Philipp Vetter, "'Ideologiefalle der Grünen' - Scheuer fordert den Bau neuer Atomkraftwerke", *Die Welt*, 27 August 2022 (in German), see https://www.welt.de/wirtschaft/article240702673/Atomkraft-Ideologiefalle-der-Gruenen-Scheuer-fordert-Bau-neuer-AKW.html, accessed 28 July 2023.

264 - *Die Welt*, "Grünen-Parteitag stimmt für Akw-Reservebetrieb – aber gegen neue Brennstäbe" 14 October 2022 (in German), see https://www.welt.de/politik/deutschland/article241608569/Gruenen-Parteitag-stimmt-fuer-Akw-Reservebetrieb-aber-gegen-neue-Brennstaebe.html, accessed 28 July 2023.

coalition partners. Thereby, all three plants, Emsland, Isar -2, and Neckarwestheim -2, were to remain on the grid until 15 April 2023, a minor win for the FDP. Supposedly to sweeten the deal for the Greens, the order included plans to draw up "ambitious legislation towards energy efficiency increases" and to politically push for an early coal-phase out in the federal state of North Rhine-Westphalia in 2030.[265] Scholz demanded that "the relevant proposed regulations [on the "stretched operations"] be presented to the cabinet as soon as possible as part of the distribution of responsibilities." Lindner said that "it is in the vital interest of our country and its economy that we maintain all our energy production capacities this winter", and Green parliamentary leaders Britta Hasselmann and Katharina Droege pointed out that the limited lifetime extension at Emsland was "unfortunate and had no factual or technical reason". All three nuclear operators positively commented on Scholz's decision, saying that now that it was clear what would be happening, they could begin planning for continued operation until mid-April 2023.[266]

On 19 October 2022, the draft bill to extend operations of Emsland, Isar-2, and Neckarwestheim-2 to 15 April 2023 received cabinet approval and was passed on to the German Bundestag. Habeck emphasized that no new fuel rods would be ordered, and that he trusted "that the FDP will stick to the [coalition] agreement and not damage the authority of the chancellor [by calling for further extensions]".[267] In the press conference following the cabinet meeting, Environment Minister Steffi Lemke (Green Party) stated:

> The phaseout of nuclear power will remain the same. Germany will finally phase out nuclear power on 15 April 2023. There will be no extension of the service life and no procurement of new fuel assemblies - and therefore no additional highly radioactive waste. The draft law will contribute to the stability of the power grid, which is compatible with nuclear safety because it limits the duration of nuclear power plant operation to a short period this winter. Even in the current energy supply crisis, we must keep an eye on the risks of nuclear power.[268]

On 11 November 2022, the Bundestag approved the 19th amendment of the Atomic Energy Act and thus stretched the operational lifetime of the three remaining nuclear power plants by three and half months. Legislation was approved with 375 votes in favor, 216 opposing (consisting of conservative parties CDU and CSU, the Left-wing party Die Linke, and several Green members of parliament). The AfD parliamentary group abstained (with one vote against).[269] During the same session, CDU and CSU put an amendment to a vote with the aim to extend the operation of the three units to 31 December 2024 to a vote, and the AfD proposed

265 - Michael Bauchmüller and Claus Hulverscheidt, "Scholz beendet Atomstreit mit", *Süddeutsche Zeitung*, 17 October 2022 (in German), see https://www.sueddeutsche.de/politik/akw-laufzeitverlaengerung-scholz-beendet-atomstreit-mit-machtwort-1.5676832, accessed 15 June 2023.

266 - Andreas Rinke, Riham Alkousaa and Tom Käckenhoff, "Germany pushes to extend lifespan of three nuclear plants -letter", *Reuters*, 17 October 2022, see https://www.reuters.com/business/energy/germany-create-legal-basis-extend-lifespan-three-nuclear-plants-letter-2022-10-17/, accessed 28 July 2023.

267 - *AFP* and *dpa*, "German Cabinet approves nuclear plant lifespan extension", as published in *Deutsche Welle*, 19 October 2022, see https://www.dw.com/en/germany-nuclear-plants-life-extension-approved-by-cabinet/a-63492302, accessed 28 July 2023.

268 - *WNN*, "German cabinet approves extended reactor operations", *World Nuclear News*, 20 October 2022, see https://www.world-nuclear-news.org/Articles/German-cabinet-approves-extended-reactor-operation, accessed 28 July 2023.

269 - Deutscher Bundestag, "Namentliche Abstimmung—Änderung des Atomgesetzes—19. AtGÄndG (Gesetzentwurf)", German Bundestag, 11 November 2022 (in German), see https://www.bundestag.de/parlament/plenum/abstimmung/abstimmung?id=817, accessed 28 July 2023.

two legislative measures for unlimited operational lifetimes and increased funding into nuclear research. All three propositions failed to gather a majority.[270]

In the days and weeks leading up to the final closure of the three reactors, the debate continued. Bavarian prime minister Markus Söder (CSU) called for all three plants to operate until 2030, saying that the phaseout was a "mistake" and even a "sin".[271] Leading member of the FDP Wolfang Kubicki continued to usher warnings about hypothetical consequences of the phaseout:

> Shutting down the world's most modern and safest nuclear power plants in Germany is a dramatic mistake that will still have painful economic and ecological consequences for us.[272]

Parliamentary leader of the FDP, Christian Dürr, suggested that three reactors remain in a "strategic reserve" and delay decommissioning because "one could switch them back on if a difficult [energy supply] situation arises". This was dismissed as "utter nonsense" by prominent Green party member and former Environment Minister Jürgen Trittin.[273]

Outside of the political debate, a shift seemed to be emerging in German society from a general acceptance of the phaseout to gradual opposition, leading to, depending on the poll, up to two thirds of Germans surveyed in the Spring of 2023 opposing the planned phaseout, citing fears of energy security and rising prices[274], although official Government simulations (see above) and other calculations had come to the conclusion that there would be little to no effect on electricity prices or security of supply.[275] Nonetheless, prominent industry representatives issued warnings of rising electricity prices and the subsequent locational disadvantage of Germany.[276] Chief of the German Technical Inspection Association (TÜV) Joachim Bühler became a prominent advocate for lifetime extensions and even restart of closed reactors after the South-German association TÜV Süd had issued a note on the technical feasibility of lifetime extensions at Isar-2 and the restart of Gundremmingen-C.[277] This 7-page paper however was dismissed as "biased" in a legal opinion commissioned by Greenpeace, mainly due to the neglect of necessary safety inspections and expected ensuing measures that would have needed to be implemented, as the last in depth decennial inspection had been conducted

270 - Deutscher Bundestag, "Bundestag beschließt AKW-Laufzeitverlängerung bis Mitte April 2023", 11 November 2022 (in German), see https://www.bundestag.de/dokumente/textarchiv/2022/kw45-de-atomgesetz-freitag-917474, accessed 28 July 2023.

271 - David Rech, "Söder fordert Laufzeitverlängerung von Atomkraftwerken", *Zeit Online*, 13 April 2023 (in German), see https://www.zeit.de/politik/deutschland/2023-04/markus-soeder-laufzeit-kernkraftwerk-isar-2, accessed 28 July 2023.

272 - Thorben Ostermann, "Ringen bis zur letzten Minute", *tagesschau.de*, 12 April 2023 (in German), see https://www.tagesschau.de/inland/atomausstieg-debatte-105.html, accessed 28 July 2023.

273 - Ibidem.

274 - *Zeit Online*, "Mehrheit der Deutschen gegen Atomausstieg" *Zeit Online*, 14 April 2023 (in German), see https://www.zeit.de/wirtschaft/2023-04/mehrheit-deutschland-gegen-abschaltung-kernkraftwerk-atomkraft, accessed 31 July 2023.

275 - Mathias Mier, "Erdgas- und Strompreise, Gewinne, Laufzeitverlängerungen und das" ifo Schnelldienst, 14 September 2022 (in German), see https://www.ifo.de/publikationen/2022/aufsatz-zeitschrift/erdgas-und-strompreise-gewinne-laufzeitverlaengerungen, accessed 31 July 2023.

276 - Birgit Marschall, "Wirtschaft warnt vor unkalkulierbaren Risiken durch Atomausstieg", *Rheinische Post*, 11 April 2023 (in German), see https://rp-online.de/politik/deutschland/atomausstieg-15-april-wirtschaft-warnt-vor-unkalkulierbaren-risiken_aid-88091033, accessed 31 July 2023.

277 - TÜV-Süd, "Bewertung der konkreten erforderlichen technischen Maßnahmen für einen Weiterbetrieb des KKI 2 bzw. eine Wiederinbetriebnahme des Blocks C des KRB II", commissioned by the Bavarian Ministry for Environment and Consumer Protection, see https://www.stmuv.bayern.de/themen/reaktorsicherheit/doc/tuev_stellungnahme.pdf, accessed 3 August 2023.

in 2009.[278] The debate as a whole was criticized by other experts as a "phantom debate" as technical, organizational, financial and liability-related issues were too high to extend operational lifetimes or even restart reactors.[279]

On 15 April 2023, Emsland, Neckarwestheim-2, and Isar-2 were finally disconnected from the grid. Since then, decommissioning preparation or actual dismantling has commenced at all three plants (see Decommissioning Status Report).

In the months after the reactor closures, trade data showed that Germany was importing more electricity than it exported—a situation due to price developments on the European power market and not because of capacity shortages—that nevertheless swiftly led German conservative and liberal voices, and the French minister for the energy transition, to criticizing Germany's energy policy.[280] Some political actors criticized Germany as the "only wrong-way driver" in energy policy and demanded the restart of up to eight closed reactors.[281] This number comes from a report issued by pro-nuclear Radiant Energy Group that claims that eight reactors could be restarted in as soon as nine months for costs of €100–200 million each (US$109–218 million).[282] Given that most German reactors are well underway with decommissioning (See Decommissioning Status Report), and that the utilities have repeatedly confirmed their decision to move away from nuclear power, these estimations seem unrealistic.

278 - Ulrich Wollenteit, "Stellungnahmen zu der von der TÜV SÜD Industrie Service GmbH erstellten und auf der Seite des Staatsministeriums für Umwelt und Verbraucherschutz des Freistaat Bayern veröffentlichten ‚Bewertung der konkreten erforderlichen technischen Maßnahmen für einen Weiterbetrieb des KKI 2 bzw. eine Wiederinbetriebnahme des Blocks C des KRB II'", Rechtsanwälte Günther, July 2022, op. cit.

279 - Jan Schneider, "Brauchen wir deutsche AKWs im Winter 23/24?", *ZDF*, 4 January 2023 (in German), see https://www.zdf.de/nachrichten/politik/akw-debatte-laufzeiten-100.html, accessed 31 July 2023.

280 - Bettina Menzel, "Wind- statt Atomkraft: Frankreich kritisiert Deutschlands Energiepolitik", *Merkur,* 10 July 2023 (in German), see https://www.merkur.de/wirtschaft/atomstrom-stromimporte-wind-atomkraft-frankreich-kritik-deutschland-energiepolitik-92385617.html, accessed 31 July 2023.

281 - *Kyffhäuser Nachrichten*, "Deutschland ist der einzige Geisterfahrer", 25 July 2023 (in German), see https://www.kyffhaeuser-nachrichten.de/news/news_lang.php?ArtNr=331073, accessed 31 July 2023.

282 - Mark Nelson and Richard Ollington, "Restart of Germany's Reactors: Can it be Done?", Radiant Energy Group, July 2023, see https://www.radiantenergygroup.com/reports/restart-of-germany-reactors-can-it-be-done, accessed 31 July 2023.

The 65 Years of the German Nuclear Program 1958–2023

In 1955, a ten-year post-World War II moratorium on reactor construction and uranium procurement ended in the Federal Republic of Germany (FRG), and the government swiftly opened the first German nuclear research facility in Karlsruhe in 1956 and began constructing the first research reactor in Garching, Bavaria, only one year later. On 1 January 1960, the first Atomic Energy Act came into force and the first West German demonstration reactor VAK Kahl came online in 1961.

The first commercial power plant however was built in the German Democratic Republic (GDR): Rheinsberg began electricity production in 1966. The first West German commercial plant, Gundremmingen-A, was connected to the grid seven months later, in 1966, but closed in 1977 following a radioactive steam leak.[283] Most German nuclear power plants began construction in the late 1960s to early 1980s, and were met by major opposition through the whole of society (see above).[284] Most of these reactors were light-water reactors, while some attempts at establishing other technologies were made, e.g., the fast breeder SNR-300 in Kalkar, or the pebble-bed high-temperature reactor (THTR-300) in Hamm-Uentrop, they never properly operated.[285] Kalkar never started up and has since been transformed into an amusement park.[286]

In 1989, the total installed capacity of East and West German nuclear power plants reached its maximum of 22.9 GW. After unification, mostly due to liability concerns, former GDR plants at Greifswald and Rheinsberg were closed (and have been undergoing decommissioning since; see Decommissioning Status Report), and construction at three additional units at Greifswald and two at Stendal was halted.[287] Before the "consensus agreement" was negotiated by the SPD-Greens government of 1998-2002, West German reactors Lingen, Mülheim-Kärlich, and Würgassen had been taken off the grid for various reasons.[288] Reactors Stade and Obrigheim were the only two that were closed as a consequence of the agreement, but by August 2011, another eight were closed resulting from the reinstated phaseout legislation. Further plants were closed successively between 2015, and mid-2023 (see Figure 38).

283 - Lena-Jülide Camurdas et al., "Einfach mal abschalten - und dann? Die Geschichte der deutschen Atomkernkraft und ihr radioaktives Erbe", *Oekom Verlag, 2023*.

284 - Joachim Radkau and Lothar Hahn, "Aufstieg und Fall der deutschen Atomwirtschaft", *Oekom Verlag, 2013*.

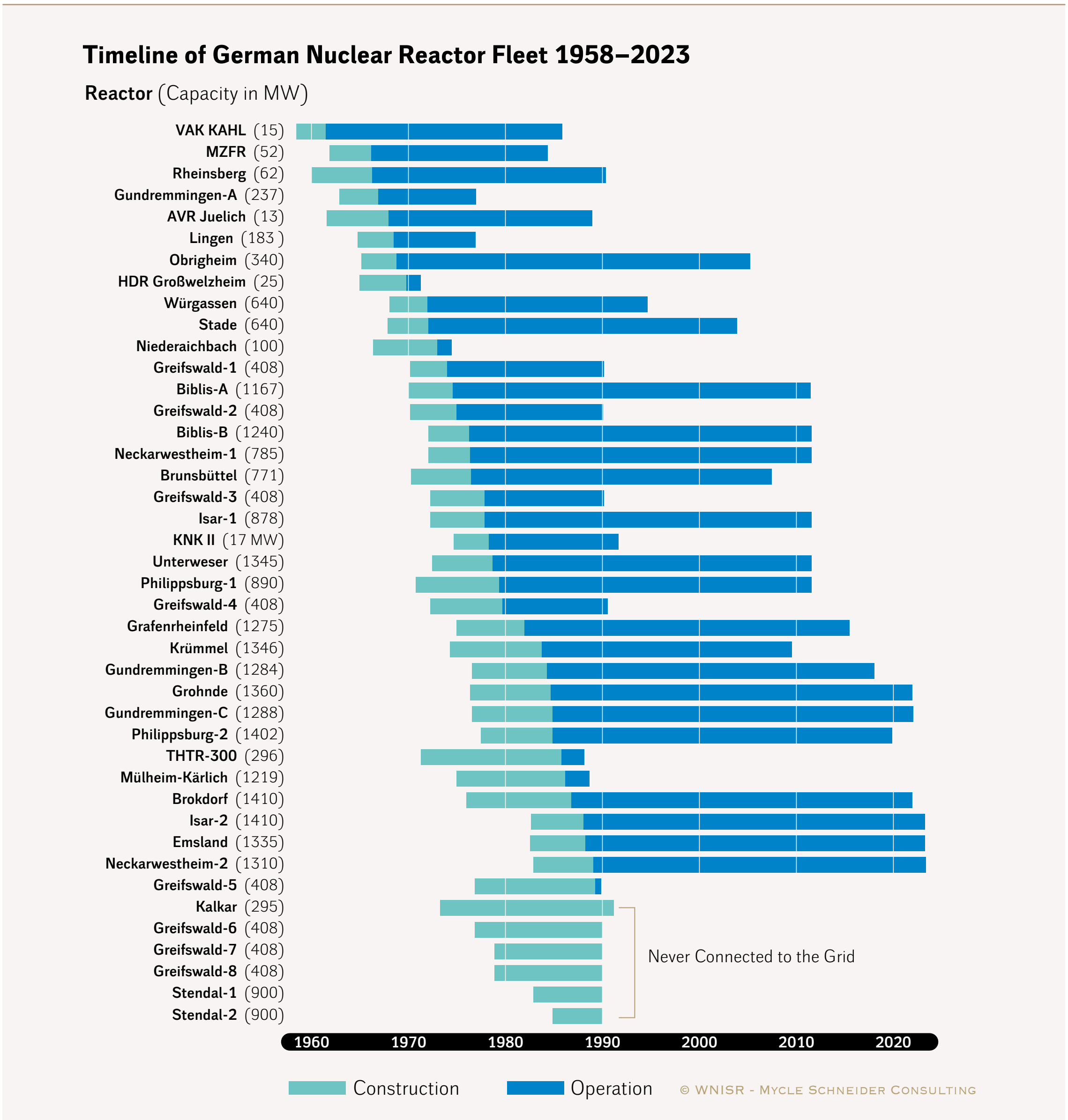
285 - Alexander Wimmers, Fanny Böse et al., "Plans for Expanding Nuclear Power Plants Lack Technological and Economic Foundations", *DIW Weekly Report*, 2023, see http://www.diw.de/sixcms/detail.php?id=diw_01.c.868677.de, accessed 19 May 2023.

286 - *WDR*, "Wunderland Kalkar hat neuen Eigentümer", 3 August 2022 (in German), see https://www1.wdr.de/nachrichten/rheinland/neuer-eigentuemer-wunderland-kalkar-100.html, accessed 17 August 2022.

287 - *Der Spiegel*, "Mit den Jahren spröde", 18 February 1990 (in German), see https://www.spiegel.de/wirtschaft/mit-den-jahren-sproede-a-37c8e961-0002-0001-0000-000013507395?context=issue; and Michael Hänel, "Das Ende vor dem Ende. Zur Rolle der DDR-Energiewirtschaft beim Systemwechsel 1980-1990", *G8 German Studies*, March 1998 (in German), see https://haenel.files.wordpress.com/2013/10/ddratom.pdf; both accessed 15 August 2022.

288 - Lena-Jülide Camurdas et al., "Einfach mal abschalten - und dann? Die Geschichte der deutschen Atomkernkraft und ihr radioaktives Erbe", *Oekom Verlag*, 2023.

Figure 38 · Construction and Operational History of the German Nuclear Reactor Fleet



Sources: WNISR, with IAEA-PRIS, 2023

Nuclear Power, Renewables, Fossil Fuels, and Efficiency

Germany's nuclear fleet generated 32.8 TWh net in 2022, a decline by half over the previous year after three reactors were closed at the end of 2021, and only a fraction of the peak generation of 162.4 TWh in 2001. In 2022, nuclear plants provided 6 percent of Germany's gross electricity generation, compared to the historic maximum of 35.6 percent in 1999, according to data from AGEB.[289]

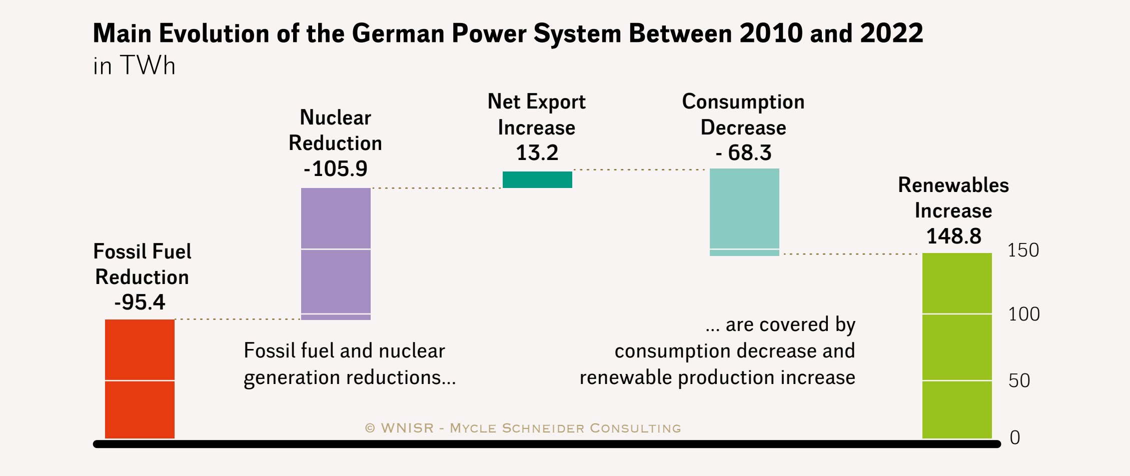
289 - AGEB, "Stromerzeugung nach Energieträgern (Strommix) von 1990 bis 2022 (in TWh) Deutschland insgesamt", Arbeitsgemeinschaft Energiebilanzen e.V./Working Group on Energy Balances, February 2023 (in German), see https://ag-energiebilanzen.de/wp-content/uploads/2023/03/STRERZ22A11_Abg_0223.pdf, accessed 29 July 2023.

Renewables generated 254 TWh (gross), a significant 8.5 percent-increase over the previous year, Consequently, the share of renewables rose five percentage points from 40.2 percent to 44.5 percent.[290] In the first half of 2023, while, due to unfavorable climatic conditions, the renewables output slightly declined (-1 percent) compared to the same period in 2022, their share rose nevertheless from 49 percent to 52 percent as consumption dropped significantly.[291]

Figure 39 summarizes the main developments of the German power system between 2010—the last year prior to the post-3/11 closure of the eight oldest nuclear reactors—and 2022.

The increase in renewables (+148.8 TWh) and the decline in consumption (-68.3 TWh) still overcompensate the decline in fossil fuel (-95.4 TWh) and nuclear generation (-105.9 TWh), allowing for an increase in net exports (+13.2 TWh).

Figure 39 · Main Developments of the German Power System Between 2010 and 2022



Sources: WNISR, based on AGEB, 2023

Developments within the fossil-fuel generating segment:

- Lignite peaked in 2013 and then declined—especially in 2019–2020—before increasing again by 20.2 percent in 2021 and another 5.3 percent in 2022. Lignite generation in 2022 thus exceeded 2019 levels by 2.2 TWh but stayed 20.4 percent below the 2010-level.
- After declining constantly between 2013 and 2019, hard coal electricity generation increased for the second year in a row, by 18 percent year on year, to 64.4 TWh remaining 45 percent below the 2010-level.
- Natural gas consumption for electricity in 2022 declined by 11.6 percent compared to 2021 to 79.8 TWh, the lowest value since 2016 and 10 percent below the 2010-level.

290 - Ibidem; and Umweltbundesamt, "Erneuerbare und konventionelle Stromerzeugung", German Environment Agency, 22 March 2023 (in German), see https://www.umweltbundesamt.de/daten/energie/erneuerbare-konventionelle-stromerzeugung, accessed 3 August 2023.

291 - Umweltbundesamt, "1. Halbjahr 2023: Weniger erneuerbarer Strom, aber Anteil steigt", German Environment Agency, 13 July 2023 (in German), see https://www.umweltbundesamt.de/themen/1-halbjahr-2023-weniger-erneuerbarer-strom-aber, accessed 3 August 2023.

Table 8 · Legal Closure Dates for German Nuclear Reactors, 2011–2023

Reactor Name (Type, Net Capacity)	Owner/Operator	First Grid Connection	End of License (latest closure date)
Biblis-A (PWR, 1167 MW) **Biblis-B** (PWR, 1240 MW) **Brunsbüttel** (BWR, 771 MW) **Isar-1** (BWR, 878 MW) **Krümmel** (BWR, 1346 MW) **Neckarwestheim-1** (PWR, 785 MW) **Philippsburg-1** (BWR, 890 MW) **Unterweser** (BWR, 1345 MW)	RWE RWE KKW Brunsbüttel [a] PreussenElektra KKW Krümmel [b] EnBW EnBW PreussenElektra	1974 1976 1976 1977 1983 1976 1979 1978	6 August 2011
Grafenrheinfeld (PWR, 1275 MW)	PreussenElektra	1981	31 December 2015 (closed 27 June 2015)
Gundremmingen-B (BWR, 1284 MW)	KKW Gundremmingen [c]	1984	31 December 2017
Philippsburg-2 (PWR, 1402 MW)	EnBW	1984	31 December 2019
Brokdorf (PWR, 1410 MW) **Grohnde** (PWR, 1360 MW) **Gundremmingen-C** (BWR, 1288 MW)	PreussenElektra/Vattenfall [d] PreussenElektra KKW Gundremmingen	1986 1984 1984	31 December 2021
Isar-2 (PWR, 1410 MW) **Emsland** (PWR, 1329 MW) **Neckarwestheim-2** (PWR, 1310 MW)	PreussenElektra KKW Lippe-Ems [e] EnBW	1988 1988 1989	15 April 2023

Sources: WNISR with IAEA-PRIS, July 2023

Notes: Krümmel and Brunsbüttel were officially closed in 2011 but had not been providing electricity to the grid since 2009 and 2007 respectively.

PWR: Pressurized Water Reactor; **BWR**: Boiling Water Reactor; **KKW**: Nuclear Power Plant (Kernkraftwerk);
RWE: Rheinisch-Westfälisches Elektrizitätswerk Power AG; **EnBW**: Energie Baden-Württemberg AG.

a - Vattenfall 66.67%, E.ON 33.33%

b - Vattenfall 50%, E.ON 50%.

c - RWE 75%, E.ON 25%.

d - E.ON 80%, Vattenfall 20%.

e - RWE 87.5%, E.ON 12.5%.

Other Nuclear Developments in Germany

The closure of the commercial nuclear power plants has not led to the end of industrial activities in the sector in Germany, in particular considering the nuclear fuel manufacturing facility in Lingen and the uranium enrichment plant in Gronau.

The facility at Lingen is operated by Advanced Nuclear Fuels GmbH (ANF), a subsidiary of French state-owned company Framatome.[292] An application to cooperate with Rosatom subsidiary TVEL which would enable ANF to manufacture fuel assemblies for Soviet-designed VVER reactors located mainly in Eastern Europe had been submitted to the German Office for Independent Competition (Bundeskartellamt) in February 2021. The application was withdrawn several days before the Russian attack on Ukraine.[293] Instead, Framatome and Rosatom founded a joint venture in France.[294] ANF has since reapplied for a license extension

292 - Framatome, "Lingen, ANF", Undated, see https://www.framatome.com/en/implantations/lingen/, accessed 29 July 2023.

293 - Andreas Wilkens, "Brennelementefabrik in Lingen: Rosatom zieht Antrag auf Beteiligung zurück", *Heise Online*, 24 February 2022 (in German), see https://www.heise.de/news/Brennelementefabrik-in-Lingen-Rosatom-zieht-Antrag-auf-Beteiligung-zurueck-6525179.html, accessed 1 August 2023.

294 - Paul Reimar, "Russland kauft sich ein", *taz*, 29 March 2023 (in German), see https://taz.de/Brennelementfabrik-in-Lingen/!5921645/, accessed 15 June 2023.

to produce hexagonal fuel rods in Lingen. This faces opposition from the responsible Environment Ministry in Lower Saxony, led by Minister Christian Meyer (Green Party) who said that "deals with Putin should be ended, [...] especially in the nuclear sector."[295]

In the past, depleted uranium hexafluoride had been transported from Gronau to Russia where it had been re-enriched,[296] these contracts had expired before the Russian attack on Ukraine.[297] Owner Urenco indicated it has since cut all ties with its last remaining (unnamed) Russian supplier.[298]

Meanwhile, the search for a final repository site for highly active nuclear waste in Germany is underway. Initial plans to select a site by 2031 were questioned in a report from the federal company in charge, the Bundesgesellschaft für Endlagerung (BGE), according to comments made in the media by the Federal Environment Ministry on 10 November 2022.[299] The overseeing Federal Office for the Safety of Nuclear Waste Management (BASE) had repeatedly urged BGE to provide plans for the process, and in December 2021, BGE had stated that there were "no signs that the goal of finding a site for the final repository by 2031 would fail."[300] In the aforementioned dedicated report, dated 28 October 2022, that was reportedly passed on by the Federal Ministry of the Environment to BASE on 17 November 2022,[301] BGE envisions site selection for 2046–2068, contradicting current legislation requiring site selection by 2031. As of December 2022, discussions between agencies were ongoing in this regard.[302] Meanwhile, BGE announced that it was experiencing delays at Schacht Konrad, a former iron ore mine that is being rebuilt as final repository for low and intermediate waste and could therefore not stick to the original plan of completion in 2027.[303]

295 - *NDR*, "Werden in Lingen bald russische AKW-Brennstäbe produziert?", *Norddeutscher Rundfunk*, 31 March 2023, see https://www.ndr.de/nachrichten/niedersachsen/osnabrueck_emsland/Fertigt-Fabrik-in-Lingen-bald-russische-Brennstaebe-fuer-AKW,lingen994.html, accessed 1 August 2023.

296 - *BBC*, "Nuclear shipment leaves Germany for Russia", *BBC News*, 24 June 2020, see https://www.bbc.com/news/world-europe-53156266, accessed 1 August 2023.

297 - *dpa*, "Landesregierung: Keine Transporte von Gronau nach Russland", as published in *Süddeutsche Zeitung* (in German), 21 March 2022, see https://www.sueddeutsche.de/wirtschaft/atomkraft-gronau-westfalen-landesregierung-keine-transporte-von-gronau-nach-russland-dpa.urn-newsml-dpa-com-20090101-220321-99-615154, accessed 1 August 2023.

298 - Urenco, "Annual Report and Accounts 2022", March 2023, see https://www.urenco.com/cdn/uploads/supporting-files/Urenco_AR2022.pdf, accessed 1 August 2023.

299 - Christoph Jähnert, "Suche nach Atommüll-Endlager dauert länger", *tagesschau.de*, 10 November 2022 (in German), see https://www.tagesschau.de/inland/innenpolitik/suche-nach-atommuell-endlager-101.html, accessed 29 July 2023.

300 - BASE, "Suche nach einem Endlager – Aktueller Stand und wie geht es weiter?", Bundesamt für die Sicherheit der nuklearen Entsorgung/Federal Office for the Safety of Nuclear Waste Management, Udpated 20 December 2022 (in German), see https://www.base.bund.de/SharedDocs/Kurzmeldungen/BASE/DE/2022/zeitplan-zwischenstand.html, accessed 19 June 2023.

301 - BASE, "Zeitliche Betrachtung des Standortauswahlverfahrens", Bundesamt für Sicherheit der nuklearen Entsorgung/Federal Office for the Safety of Nuclear Waste Management, 28 October 2022, (in German), see https://www.endlagersuche-infoplattform.de/SharedDocs/IP6/BASE/DE/20221028_Zusammenfassung_Rahmenterminplanung_und_Zeitschaetzungen.html, accessed 1 August 2023.

302 - BASE, "Suche nach einem Endlager – Aktueller Stand und wie geht es weiter?", Updated 20 December 2022, op. cit.

303 - BGE, "Fertigstellung des Endlagers Konrad verzögert sich", Press Release No.07/23 (in German), Bundesgesellschaft für Endlagerung/Federal Company for Radioactive Waste Disposal, 13 June 2023, see https://www.bge.de/de/konrad/meldungen-und-pressemitteilungen/meldung/news/2023/6/752-endlager-konrad-1/, accessed 15 June 2023.

Conclusion: From Electricity Generation to Management and Disposal of Nuclear Waste

After 75 years of nuclear power history, the last three operating nuclear power reactors were closed in April 2023. Germany has joined three other countries that have phased out national nuclear power programs, namely Italy, Kazakhstan, and Lithuania. However, some industrial nuclear activities are still ongoing, such as nuclear fuel manufacturing in Lingen and uranium enrichment in Gronau; and Germany will remain active in international organizations like the IAEA, the OECD's Nuclear Energy Agency, and the various instances of the European Union. At the same time, other topics that have so far gotten little attention are moving to the forefront, particularly nuclear facility decommissioning and nuclear waste disposal.

With hindsight, the socio-technical discussions in Germany were rather similar to those in other countries. The discussion centered around the multiple implications of a "technical controversy", i.e. safety issues related to commercial and military uses of nuclear power. The German historian Joachim Radkau noted as early as 1983 that the anti-nuclear movement was not like any other socio-political movement but that it was enshrined in a deep technical debate about the feasibility of "sustainable" nuclear power, a debate that reappears today.[304] The movement in Germany was similar to those in other countries, but it was particularly "successful": the general deployment of nuclear power plants had not been stopped in its early days but the movement succeeded in making the economic and technical complexity of the issue widely known, and developed a convincing argumentation on costs, safety, environmental, and societal issues that had not been identified elsewhere or were identified but pushed aside (like in France).[305] The initial resistance against early nuclear power applications in Wyhl (1975)—inspired by the opposition movement against the Fessenheim nuclear power plant project in France—rapidly spread to other sites. The latest construction start in Germany of a completed nuclear reactor (Neckarwestheim-2) took place in November 1982 and it was started up in January 1989.

A historical example is the decision of Germany not to pursue the plutonium route with commercial spent fuel reprocessing, as both projects, at Gorleben (Lower Saxony) in the late 1970s and at Wackersdorf (Bavaria) in the late 1980s, were abandoned after fierce opposition. Other projects were implemented despite widespread protests and were perceived by the movement as "failures", such as Brokdorf, a nuclear reactor debated since the 1970s that was brought online shortly after the 1986 Chernobyl accident.

Controversial debates about nuclear power were also at the origin of the "Energiewende", the socio-ecological transformation that started in Germany in the 1970s and provided a book title in 1980.[306] The first energy transformation scenarios suggested to end nuclear power and oil consumption but still contained significant amounts of coal. It was only after the Rio Conference (1992) and the emergence of climate considerations that the end of coal ("coal exit") gained a dominant position in the public debate. It is not far-fetched to suggest that

304 - Joachim Radkau, "Aufstieg und Krise der deutschen Atomwirtschaft 1945-1975: Verdrängte Alternativen in der Kerntechnik und der Ursprung der nuklearen Kontroverse", Rowohlt, 1983.

305 - Gabrielle Hecht, "The radiance of France: nuclear power and national identity after World War II", *MIT Press*, 2009.

306 - Florentin Krause, Hartmut Bossel and Karl-Friedrich Müller-Reissmann, "Energie-Wende: Wachstum und Wohlstand ohne Erdöl und Uran", ed. by Öko-Institut Freiburg, S. Fischer, 1980.

without the antinuclear movement the breakthrough of the "Energiewende" and the successful mass introduction of renewables might not have happened.[307]

As in other market economies, German energy companies were pushed by the government to develop nuclear power, starting with the "Gundremmingen" model of state guarantees and subsidies and ending in captured customers having to pay (high) cost-plus tariffs to their local or regional monopolistic supplier. In that context, the "liberalization" of the electricity and natural gas sectors in the 1980s and 1990s heralded the end of nuclear power investments, showing clearly that nuclear power was not competitive under market-economy conditions (see Chapter on Nuclear Economics and Finance). When the unification of East and West Germany occurred in 1990, the energy industry could have built new nuclear power plants, or it could have at least completed the ongoing projects at Greifswald/Lubmin and Stendal, inherited from the GDR. Instead, the projects were scrapped, and operating plants were closed, whereas an entire new fleet of lignite plants was built in East Germany with substantial government support. Thus, inherently, the decision to end commercial nuclear power had been taken already in 1990, the rest of the process being political struggles about distributing the significant economic rents.[308]

After the closure of the last three reactors, the discussion is now rapidly moving from commercial nuclear power—besides some marginal requests for "newbuilds" by a handful of opposition politicians in need of public profile, a few research organizations in need of funding,[309] and the usual lobby organizations and propagandists in need of attention—to challenges of decommissioning and disposal of nuclear waste. Decommissioning will take much longer and will be more expensive than planned (see Decommissioning Status Report). Disposal of nuclear waste, 62 years after the first generation of nuclear electricity, is at its very beginning, with decisions on a deep geological storage site expected in the 2040s at the earliest, and thus a final date for the disposal of the last nuclear waste container deep in the 22nd century.

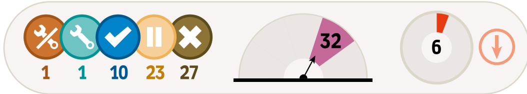
Is Germany's path an exception, a "Sonderweg", in global nuclear trajectories? Yes and no. "Yes", because the intensity of public debate was particularly high, and the societal consensus on ending commercial nuclear power generation was broader than in most other countries. Also, few other nuclear countries have set legal target dates for the phaseout of nuclear power use. However, "No" too, because there is not a single market economy that has succeeded the challenge of subsidy-free commercial nuclear deployment. Rather, the diminishing share of nuclear power can be observed globally since 1996 and more reactors have been closed over the past two decades than started up. Germany has merely accelerated a global declining trend that, despite all the newbuild announcement noise, will most likely quietly continue to erode the relevance of the nuclear industry in the energy markets.

307 - Christian von Hirschhausen, "German Energy and Climate Policies: A Historical Overview", in Energiewende "Made in Germany": Low Carbon Electricity Sector Reform in the European Context", *Springer Nature Switzerland AG*, 2018, see http://link.springer.com/10.1007/978-3-319-95126-3_2, accessed 28 March 2019.

308 - Felix Christian Matthes, "Exit economics: The relatively low cost of Germany's nuclear phase-out", *Bulletin of the Atomic Scientists*, December 2012, see http://bos.sagepub.com/content/68/6/42.abstract, accessed 15 September 2016.

309 - Ignatius Ssuuna and Cara Anna, "Rwanda will host a company's 1st small-scale nuclear reactor testing carbon-free energy approach", *The Associated Press*, 13 September 2023, see https://apnews.com/article/rwanda-nuclear-energy-canada-germany-e056293c2fb801cea18e926635ba1f13, accessed 26 October 2023.

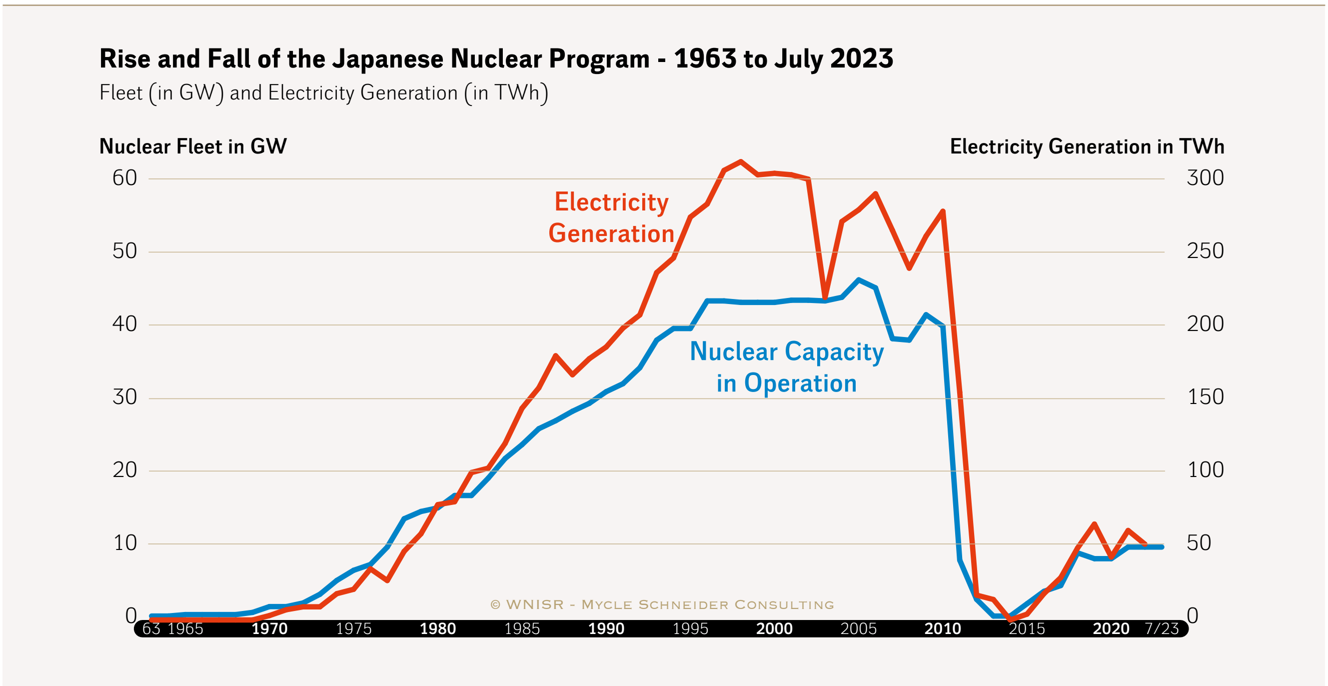
JAPAN FOCUS



Overview

During Financial Year 2022, which runs from April 2022–March 2023, the number of nuclear reactors considered "operable" remains at 10 with a capacity of 9.6 GW[310]. The average load factor for the whole Japanese nuclear power plants has worsened from 22.1 percent in 2021 to 18.7 percent in 2022 (calendar years).[311] As a result, the total nuclear power generation decreased from 61.3 TWh in 2021 to 51.9 TWh in 2022.[312] The share of nuclear power in the total power generation also decreased from 7.2 percent in 2021 to 6.1 percent in 2022.[313] (See Figure 40)

Figure 40 • Rise and Fall of the Japanese Nuclear Program



Sources: WNISR with IAEA-PRIS, 2023

The current reactor fleet consists of 33 units (33.1 GW, gross) of which 25 units (24.8 GW, gross) have applied for an operating license under the new post-Fukushima regulations.[314] So far, new licenses have been granted for 17 units while eight applications remain under review. The national safety authorities have not issued any new operating license during the past year.

310 - In English, see JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2023/07/jp-npps-operation20230710_en.pdf; or in Japanese, see JAIF, "日本の原子力発電炉（運転中、建設中、計画中など", as of 10 July 2023, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2023/07/jp-npps-operation20230710.pdf; both accessed 13 July 2023.

311 - Ibidem.

312 - PRIS–IAEA, "Country Statistics, Japan for Year 2022", Power Reactor Information System, International Atomic Energy Agency, Updated July 2023, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, accessed 1 August 2023.

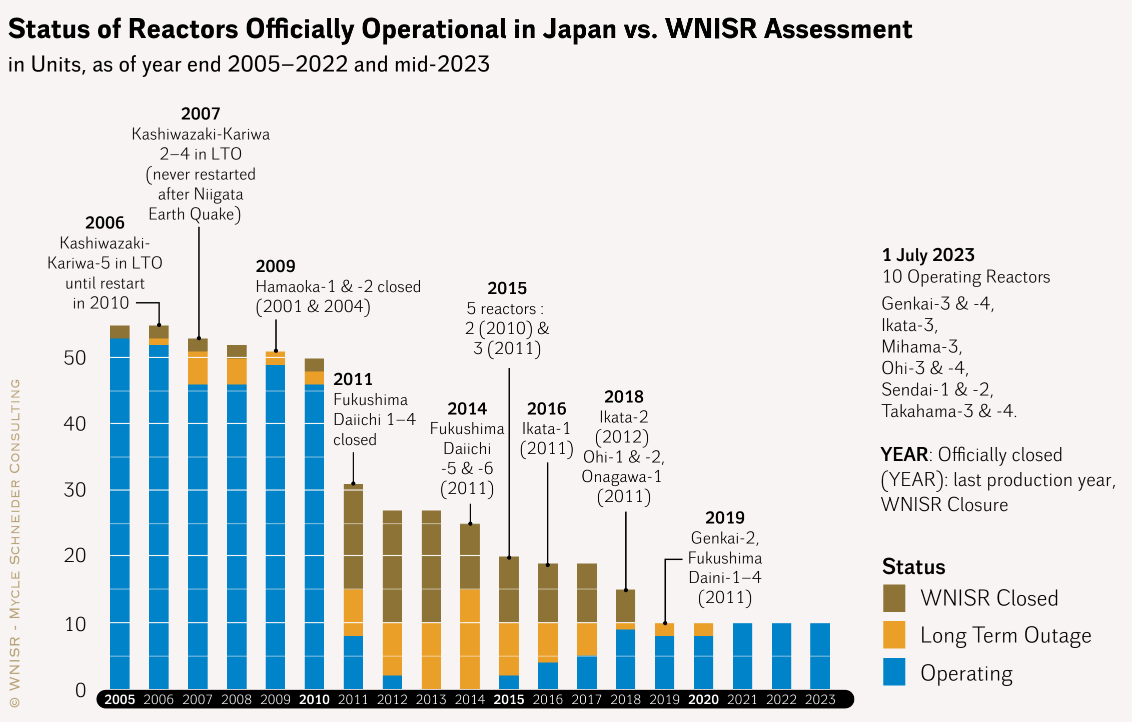
313 - Ibidem.

314 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

As of 1 July 2023, nine reactors out of 10 operable reactors (Ikata-3, Mihama-3, Takahama-3 & -4, Ohi-3 & -4, Genkai-3 & -4, Sendai-1) were operating and one was shut down for a periodic inspection (Sendai-2).

WNISR considers 23 in Long-Term Outage (LTO) and 10 in operation. In the past year, the IAEA has adopted a new category called "Suspended Operation" (see dedicated section in General Overview) and has reclassified 23 reactors that WNISR considers as in LTO. In other words, Japan and the IAEA have adopted an approach similar to the LTO concept that WNISR introduced in 2014. (See Figure 7). While the Japan Atomic Industrial Forum (JAIF) has not changed the definition of the category of "operating reactor", the report from the government to the IAEA seemed to have changed when the responsible agency as the IAEA-correspondent moved from the Nuclear Regulation Authority (NRA) to the international affairs division of the Ministry of Economy, Trade and Industry (METI)[315].

Figure 41 • Status of the Japanese Reactor Fleet



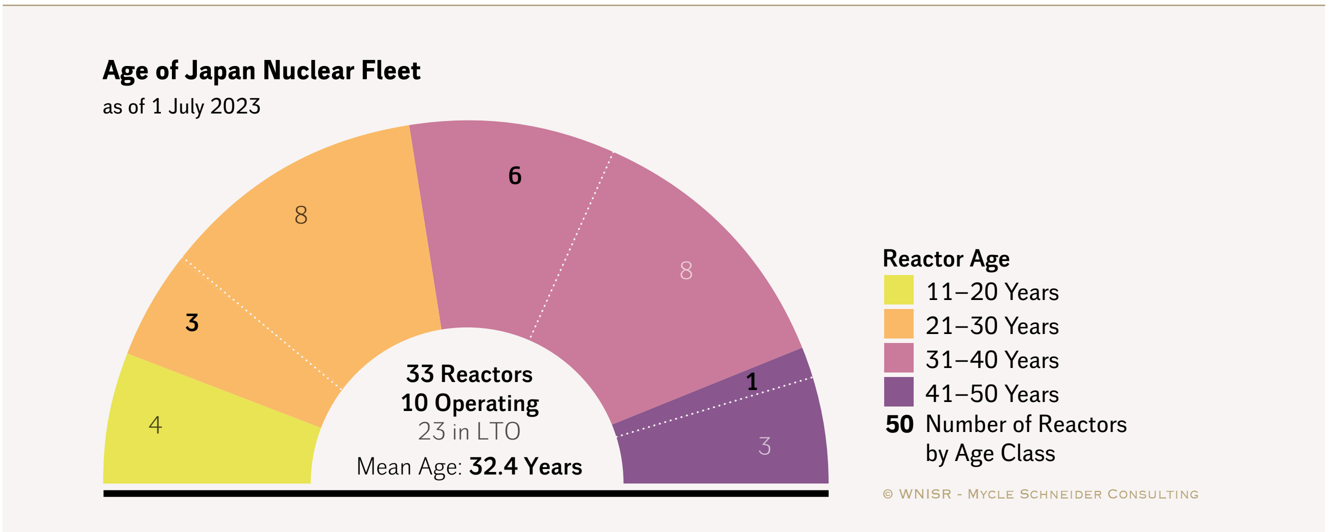
Sources: Various, compiled by WNISR, 2023

Twelve years after the Fukushima accident began, the reactors in operation are all PWRs although five BWRs (Kashiwazaki-Kariwa-6 & 7, Tokai-2, Onagawa-2, and Shimane-2) have received confirmation from the NRA to satisfy new regulatory requirements set by NRA in 2013.

As of mid-2023, the Japanese nuclear fleet consisting of 33 units including 23 in LTO had reached a mean age of 32.4 years, with 18 units over 31 years (see Figure 42).

315 - Personal communication with NRA and METI, July 2022.

Figure 42 · Age distribution of the Japanese Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2023

Tokyo Electric Power Co.'s (TEPCO's) Kashiwazaki-Kariwa-6 was the first BWR to receive approval from NRA on 27 December 2017. However, due to lack of approval from Niigata Prefecture as well as due to nuclear security violations in 2021, it is not known when the reactors at this site will restart operating. On 17 May 2023, the NRA decided to maintain its ban on moving fresh nuclear fuel within the plant. TEPCO planned to restart the plant in October 2023, but that is impossible without moving nuclear fuel. The NRA imposed the ban in April 2021 after they found that TEPCO had failed to take adequate security measures against the threat of nuclear terrorism (see detailed explanation in WNISR2022). The NRA inspected 27 places but said that the plant still had problems in four areas.[316] On 28 June 2023, Dr. Shinsuke Yamanaka, Chairperson of NRA, stated that "We need to confirm whether the major violations are being used as lessons learned, and how the organizational culture and safety culture has been affected. If there are any additional safety-related changes in TEPCO's activities, we would like to see them as well" when NRA investigates further regarding TEPCO's qualification as an operator of Kashiwazaki-Kariwa nuclear power plant. The NRA maintained its ban on loading fresh fuel because of violation of nuclear security regulations in 2022.[317]

Japan Atomic Power Co's Tokai-2 was the first BWR to get lifetime-extension approval from NRA in November 2018 but currently the work for installation of a Specialized Safety Facility (SSF) against terrorism is underway. The facility is planned to be completed in September 2024.[318] Tohoku Electric Power's Onagawa-2 received official approval by NRA of conformity to new regulatory requirements on 26 February 2020, and work on remaining safety measures is expected to be completed in November 2023. It is planned to restart operation in February 2024.[319] Chugoku Electric Power Co's Shimane-2 received approval from

316 - Keitaro Fukuchi, Ryo Sasaki and Shiki Iwasawa , "NRA's fuel ban could delay TEPCO's reactor restart plan", *The Asahi Shimbun*, 18 May 2023, see https://www.asahi.com/ajw/articles/14911086, accessed 27 June 2023.

317 - *BSN*, "Toden, 'Genpatsu Unten no Tekikakusei' Saikakunin ni Tsuite Gensiryoku Kiseii Yamanaka Iinncho 'Ookina Ihan ga Kyokun toshite ikasareteiruka'", *Niigata Broadcasting Co.*, 28 June 2023 (in Japanese), see https://newsdig.tbs.co.jp/articles/bsn/568758?display=1, accessed 29 June 2023.

318 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

319 - Ibidem.

NRA on 15 September 2021 and received local governor's approval in June 2022.[320] But because of delay in safety related work, Chugoku Electric Power announced that it will delay the restart of operation until 2024.[321]

Kansai Electric Power Co (KEPCO) has the largest number of reactors (seven in total, all PWRs) of which five (Mihama-3, Takahama-3 and -4, Ohi-3 and -4) are currently operating (as of July 2023). Mihama-3 license extension to 60 years was granted on 16 November 2016.[322] For both Takahama-3 and-4, KEPCO applied for license extension beyond 40 years on 25 April 2023. The current 40-year license will expire in 2025 for both reactors.[323]

Shikoku Electric Power's Ikata-3 reconnected to the grid on 26 May 2023 following regular inspection which started on 23 February 2023.[324]

Kyushu Electric Power Co's Genkai-3 was shut down on 21 January 2022, and operation of SSF started on 5 December 2022 while the set deadline was 24 August 2022. It was reconnected to the grid on 12 December 2022.

Genkai-4 was shut down on 30 April 2022 for regular inspection and resumed operation on 13 July 2022.[325] It was shut down again on 12 September 2022, as it could not meet the SSF deadline of 13 September 2022. SSF was finally available on 2 February 2023 and power generation resumed on 9 February 2023. Both Sendai-1 and -2 applied license extensions beyond 40 years on 12 October 2022. Licenses will expire on 3 July 2024 for Sendai-1 and on 27 November 2025 for Sendai-2.

As of July 2023, Takahama-1[326] and -2 were scheduled to restart in fall of 2023 after NRA approved a beyond 40-year operating license for both reactors on 20 June 2016. Work on safety measures was completed on the two units on 18 September 2020 and on 31 January 2022 respectively. The deadline for the installation of SSFs for the two units was 9 June 2021. Takahama-1 is scheduled to resume power generation in early August 2023 followed by Takahama-2 in mid-September 2023.[327]

As no additional reactor has been declared for permanent closure during the past year, the total number of closed reactors remains unchanged at 27 reactors[328] (including 21 reactors closed because of the Fukushima accidents, as shown on Table 9).

320 - *The Asahi Shimbun*, "Governor of Shimane agrees to restart idled nuclear reactor", 2 June 2022, see https://www.asahi.com/ajw/articles/14635842, accessed 27 June 2023.

321 - *NHK News Web*, "島根原発２号機 安全対策工事完了予定見直し 再稼働に影響か" ["Shimane Nuclear Power Plant Unit No. 2 safety work completion schedule revised, possibly affecting resumption of operations"], *Japan Broadcasting Corporation*, 22 June 2023 (in Japanese), see https://www3.nhk.or.jp/lnews/matsue/20230622/4030016297.html, accessed 27 June 2023.

322 - JAIF, "NRA Approves Extension of Operating Lifetime for Mihama-3 through 2036", Japan Atomic Industrial Forum, 17 November 2016, see https://www.jaif.or.jp/en/news/2262, accessed 8 August 2023.

323 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

324 - Ibidem.

325 - *Kyodo News*, "Kyuden, Genkai 4 go-ki no hatsuden saikai, Jyukyu hippaku ni taio", as published by *Yahoo! Japan* (in Japanese), 13 July 2022, see https://news.yahoo.co.jp/articles/4a27a8e5063dee0e5e4c238fe264a14f0b4ee132, accessed 25 July 2022.

326 - Takahama-1 was reconnected to the grid on 2 August 2023, being the 11th reactor to restart since 3/11; see Nanako Takehara, "Restarted Takahama-1 Now Operating Beyond 40 Years, the Second Case in Japan", Japan Atomic Industrial Forum, 1 September 2023, see https://www.jaif.or.jp/en/news/6711, accessed 29 September 2023.

327 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

328 - Ibidem.

Legal Cases Against the Restart of Reactors

The legal cases against operation of existing reactors continue. The following are two key decisions made during the past year, both of which rejected "injunction" appeals made by local residents.

On 24 March 2023, Hiroshima High Court rejected local residents' "injunction" appeal to stop the restart of Ikata-3 nuclear power plant operated by Shikoku Electric Power Co. Ikata-3 was shut down for regular inspection from 23 February 2023 until 19 June 2023.[329] The case was brought by seven residents of Hiroshima and Ehime prefectures who live between 60 and 130 km from the reactor. The main focal issue was whether the operator's estimate of seismic ground motion was adequate or not. As reported in WNISR2022, the Hiroshima district court dismissed similar requests and ruled against the injunction. The Hiroshima Hight Court followed the district court decision and ruled that Shikoku Electric's seismic estimate was to be considered adequate.[330]

On 24 May 2023, the Sendai district court rejected the appeal for injunction against the restart of Tohoku Electric Power Co's Onagawa-2 nuclear power plant in Miyagi prefecture. Tohoku Electric Power Co plans to restart the reactor in February 2024 after a long shutdown period after the Fukushima nuclear accidents in 2011. The main issue was the adequacy of the evacuation plan. The case was brought by 17 residents of the city of Ishinomaki, claiming the evacuation plans prepared by the city and prefectural government are not sufficient. But the ruling was not based on the adequacy of the evacuation plans, but on the dismissal of the notion of "specific danger" of a nuclear accident the plaintiffs claimed. The Court said that "it cannot be assumed that a specific danger of an accident exists", as the burden of proof is with the plaintiffs. Noboru Hara, 81-year-old spokesperson for the plaintiffs said they will "consult with lawyers with a view to filing an appeal."[331]

Reactor Closures and Spent Fuel Management

No additional reactor(s) operating (or in outage) at the time of the Fukushima events, were formally declared for decommissioning in the year to 1 July 2023. The 11 commercial Japanese reactors now confirmed to be decommissioned (not including the Monju Fast Breeder Reactor and the ten Fukushima reactors) had a total generating capacity of 6.4 GW, representing about 15 percent of Japan's officially operating nuclear capacity as of March 2011. Together with the ten Fukushima units, the 21 units total 15.2 GW or just under 35 percent of nuclear capacity prior to 3/11 (see Figure 41 and Table 9). In total, Japan has 27 closed reactors (17.1 GW) (see Case study on Japan in Decommissioning Status Report).

Regarding spent fuel from demonstration reactors, on 24 June 2022, the Japan Atomic Energy Agency (JAEA) signed a final €250 million (US$$_{2022}$263 million)-contract with French

329 - Ibidem; and *Kyodo News*, "Japan court rules against restarting nuclear power plant in Hokkaido", 31 May 2022, see https://english.kyodonews.net/news/2022/05/44f2349084b6-urgent-court-rules-against-restarting-nuclear-power-plant-in-hokkaido.html, accessed 26 July 2022.

330 - *Kyodo News*, "Court rejects residents' call to halt western Japan nuclear reactor", 24 March 2023, see https://english.kyodonews.net/news/2023/03/3fffc0218efa-court-rejects-residents-call-to-halt-western-japan-nuclear-reactor.html, accessed 28 July 2023.

331 - *Kyodo News*, "Court rejects case opposing restart of Miyagi Pref. nuclear plant", 24 May 2023, see https://english.kyodonews.net/news/2023/05/e4cae03c78b5-court-rejects-case-opposing-restart-of-miyagi-pref-nuclear-plant.html, accessed 28 July 2023.

company Orano for the transport and reprocessing of spent fuel from the Fugen ATR,[332] which first reached criticality in 1978 and was closed in 2003. Work was set to start in 2023 and be completed by March 2027,[333] but no update on ongoing works has been communicated as of July 2023. Prior to the final agreement, on 20 June 2022, it was reported that JAEA would transfer to France the plutonium extracted from spent fuel from its Fugen reactor.[334] (See WNISR2022 – Japan Focus for more detail).

In March 2022, similar reprocessing contracts with Orano were said to being proposed for spent fuel from the Monju FBR[335]—which first reached criticality in 1994, was connected to the grid for only three and a half months when it had an accident in December 1995, and was officially closed in 2017—but no official agreement or decision was communicated as of mid-2023. Meanwhile, spent fuel removal has been completed and by 22 April 2022, all spent fuel from Monju had been moved to a temporary storage tank filled with liquid sodium and relocated to a water-cooled storage pool by October 2022.[336]

JAEA, which manages the decommissioning work of Monju, plans to start the extraction of the liquid sodium from the reactor in 2023, and eventually transfer the spent fuel "to domestic and foreign operators with licenses for reprocessing in Japan or in countries with which Japan has signed agreements for cooperation on the peaceful uses of nuclear energy."[337]

On 13 June 2023, Kansai Electric Power Co (KEPCO), along with the Federation of Electric Power Company (FEPCO), announced that they will ship 200 tons of spent fuel (10 tons of spent LWR-MOX fuel and 190 tons of usual spent uranium fuel[338]) to France for "demonstration" of spent MOX fuel reprocessing. KEPCO promised to Fukui Prefecture that they will remove spent fuel from the prefecture and find a candidate site for interim storage of spent fuel outside of Fukui prefecture by the end of 2023. Although 200 tons is only about 5 percent of the spent fuel KEPCO stores in Fukui prefecture. Nozomu Mori, President of KEPCO, said that "it carries an equal weight to temporary storage in that spent nuclear fuel will be transported out of the prefecture. The promise has been fulfilled for now." It is not clear whether Fukui prefecture will be satisfied with this explanation and the plan for the rest of spent fuel stored in Fukui prefecture is not known yet.[339]

332 - Orano, "Orano wins a contract for the transport and recycling of Japanese used fuel", Press Release, 27 June 2022, see https://www.orano.group/en/news/news-group/2022/june/orano-wins-a-contract-for-the-transport-and-recycling-of-japanese-used-fuel; and *WNN*, "Orano contracted to reprocess Fugen used fuel", *World Nuclear News*, 28 June 2022, see https://www.world-nuclear-news.org/Articles/Orano-contracted-to-reprocess-Fugen-used-fuel; both accessed 12 July 2023.

333 - FUGEN Decommissioning Engineering Center, "Efforts to Spent Fuel Transport", Japan Atomic Energy Agency, Undated, see https://www.jaea.go.jp/04/fugen/en/haishi/spentfuel/, accessed 11 July 2023.

334 - *Jiji News*, "Japan to Give Plutonium from Spent Fuel to France", 20 June 2022, see https://sp.m.jiji.com/english/show/20405#google_vignette, accessed 28 June 2023.

335 - *Jiji Press*, "Monju's Spent Nuclear Fuel to Be Shipped to France from FY 2034", 30 March 2022, see https://sp.m.jiji.com/english/show/18870, accessed 11 July 2023.

336 - *WNN*, "Defuelling completed at Japan's Monju reactor", *World Nuclear News*, 21 October 2022, see https://www.world-nuclear-news.org/Articles/Defuelling-completed-at-Japan-s-Monju-reactor, accessed 11 July 2023.

337 - *NEI Magazine*, "Defuelling completed at Japan's Monju FBR", *Nuclear Engineering International*, 25 October 2022, see https://www.neimagazine.com/news/newsdefuelling-completed-at-japans-monju-fbr-10115967, accessed 11 July 2023.

338 - Both types of fuel would be reprocessed together in order to "dilute" the MOX fuel and reduce criticality risks of higher plutonium contents in the solution.

339 - *NHK World News*, "KEPCO unveils plan to ship 5 percent of spent nuclear fuel to France", 13 June 2023, see https://www3.nhk.or.jp/nhkworld/en/news/20230613_07/index.html, accessed 28 June 2023; and Takashi Yoshida, Kenji Oda, Shuichi Doi and Chiaki Ogihara, "Kansai Electric takes heat for half-truths over spent nuke fuel", *The Asahi Shimbun*, 29 June 2023, see https://www.asahi.com/ajw/articles/14944345, accessed 12 July 2023.

Table 9 · Official Reactor Closures Post-3/11 in Japan (as of 1 July 2023)

Operator	Reactor	Capacity MW	Startup Year	Closure Announcement[(a)] dd/mm/yy	Official Closure Date[(b)] dd/mm/yy	Last Production	Age[(c)]
TEPCO	Fukushima Daiichi-1 (BWR)	439	1970	-	19/04/12	2011	40
	Fukushima Daiichi-2 (BWR)	760	1973	-	19/04/12	2011	37
	Fukushima Daiichi-3 (BWR)	760	1974	-	19/04/12	2011	36
	Fukushima Daiichi-4 (BWR)	760	1978	-	19/04/12	2011	33
	Fukushima Daiichi-5 (BWR)	760	1977	19/12/13	31/01/14	2011	34
	Fukushima Daiichi-6 (BWR)	1 067	1979	19/12/13	31/01/14	2011	32
	Fukushima Daini-1 (BWR)	1 067	1981	31/07/19	30/09/19	2011	30
	Fukushima Daini-2 (BWR)	1 067	1983	31/07/19	30/09/19	2011	28
	Fukushima Daini-3 (BWR)	1 067	1984	31/07/19	30/09/19	2011	26
	Fukushima Daini-4 (BWR)	1 067	1986	31/07/19	30/09/19	2011	24
KEPCO	Mihama-1 (PWR)	320	1970	17/03/15	27/04/15	2010	40
	Mihama-2 (PWR)	470	1972	17/03/15	27/04/15	2011	40
	Ohi-1 (PWR)	1 120	1977	22/12/17	01/03/18	2011	34
	Ohi-2 (PWR)	1 120	1978	22/12/17	01/03/18	2011	33
KYUSHU	Genkai-1 (PWR)	529	1975	18/03/15	27/04/15	2011	37
	Genkai-2 (PWR)	529	1980	13/02/19	13/02/13	2011	31
SHIKOKU	Ikata-1 (PWR)	538	1977	25/03/16	10/05/16	2011	35
	Ikata- 2 (PWR)	538	1981	27/03/18[(d)]	27/03/18	2012	30
JAEA	Monju (FBR)	246	1995	12/2016[(e)]	05/12/17	LTS[(f)] since 1995	-
JAPC	Tsuruga -1 (BWR)	340	1969	17/03/15	27/04/15	2011	41
CHUGOKU	Shimane-1 (PWR)	439	1974	18/03/15	30/04/15	2010	37
TOHOKU	Onagawa-1 (BWR)	498	1983	25/10/18	21/12/18[(g)]	2011	27
TOTAL: 22 Reactors /15.5 GWe							

Sources: JAIF and JANSI, compiled by WNISR, 2023

Notes: This table only lists the 22 reactors closed after the Fukushima accidents, thus not including the Fugen Advanced Thermal Reactor (ATR), Japan Power Demonstration Reactor (JPDR), as well as Hamaoka-1 & -2 (Chubu Electric Power) and Tokai-1 (JAPCo).

BWR: Boiling Water Reactor; **PWR**: Pressurized Water Reactor; **FBR**: Fast Breeder Reactor; **LTS**: Long-Term Shutdown.

JAPC: Japan Atomic Power Company; **JAEA**: Japan Atomic Energy Commission

(a) – Unless otherwise specified, all announcement dates from JANSI, "Licensing status for the Japanese nuclear facilities", Japan Nuclear Safety Institute, 26 February 2020, see

, accessed 27 July 2020.

(b) – Unless otherwise specified, all closure dates from individual reactors' page via JAIF, "NPPs in Japan", Japan Atomic Industrial Forum, see http://www.jaif.or.jp/en/npps-in-japan/, as of 27 July 2020.

(c) – Note that WNISR considers the age from first grid connection to last production day.

(d) – *WNN*, "Shikoku decides to retire Ikata 2", *World Nuclear News*, 27 April 2018, see http://www.world-nuclear-news.org/C-Shikoku-decides-to-retire-Ikata-2-2703184.html, accessed 22 July 2018.

(e) – *The Mainichi*, "Japan decides to scrap trouble-plagued Monju prototype reactor", 21 December 2016, see http://mainichi.jp/english/articles/20161221/p2g/00m/0dm/050000c, accessed 21 December 2016.

(f) – The Monju reactor was officially in Long-Term Shutdown or LTS (IAEA-Category Long Term Shutdown) since December 1995. Officially closed in 2017.

(g) – The decision to close the reactor was announced in October 2018.

Japan Steel Works (JSW) Falsification Incident Update

On 9 May 2022, Japan Steel Works (JSW), a global leading manufacturer of key nuclear reactor components, published a report on the discovery of "inappropriate conduct in quality inspections" at its subsidiary, Japan Steel Works M&E and announced that it would establish a special investigating committee.[340]

On 14 November 2022, the special investigating committee submitted its findings to company management. The report said that a total of 449 inappropriate conducts, including data falsification of inspection data, and 20 incidents involving components related to nuclear power had been identified[341] (see Table 10). Out of 20, six cases were related to French EDF orders, including the nozzle support ring of a steam generator of the Cruas-1 reactor. EDF claimed that its own analysis showed that the integrity of the equipment was not jeopardized.[342] On 29 November 2022, JSW issued a statement saying that eight senior executives, including the former and current presidents of the company, will receive corporate punishment (salary cuts by 30 percent for three months).[343]

On 9 May 2023, Mr. Toshio Matsuo, President of JSW issued a statement on this issue, saying that the company "will reform the system so that no single department manages everything from specifications and delivery dates to even customer relations, in order to transform the organizational structure".[344]

340 - JSW, "The discovery of inappropriate conduct in quality inspections on some of our subsidiaries' products and establishment of the Special Investigating Committee", Japan Steel Works, 9 May 2022, see https://www.jsw.co.jp/news/news_file/file/20220509_news.pdf, accessed 4 August 2023.

341 - *NHK*, "Nihon Seikosho Kogaisha ga Kensakekka Kaizan nado 449 ken fusei kakunin", 14 November 2022 (in Japanese), see https://www3.nhk.or.jp/news/html/20221114/k10013891391000.html, accessed 4 August 2023.

342 - ASN, "Irregularities in equipment manufacturing at Japan Steel Works", Autorité de Sûreté Nucléaire/French Nuclear Safety Authority, 26 January 2023, see https://www.french-nuclear-safety.fr/asn-informs/news-releases/irregularities-in-equipment-manufacturing-at-japan-steel-works, accessed 4 August 2023.

343 - Satoru Eguchi, "品質検査の不正で現・前社長ら役員8人に報酬減額処分　日本製鋼所" ["Eight executives, including the current and former presidents, have had their compensation reduced due to quality inspection irregularities"], *The Asahi Shimbun*, 29 November 2022 (in Japanese), see https://digital.asahi.com/articles/ASQCY6R5HQCYULFA02K.html, accessed 4 August 2023.

344 - Toshio Matsuo, "In Response to Inappropriate Conduct in Quality Inspections by Our Subsidiary", Japan Steel Works, 9 May 2023, see https://www.jsw.co.jp/news/news_file/file/20230509_news_en.pdf, accessed 4 August 2023.

Table 10 · Typology of Falsification Cases at Japan Steel Works

Product Groups	Products	Type of Inappropriate Conduct	Number of Cases and Times of Occurrences
Power Product	Rotors, Ring materials	Falsification, fabrication, or misstatement of inspection results and analysis values	341 Cases (1998–2021)
Nuclear Energy Products [(a)]	Disc materials, Head materials	Falsification of dimensional records, falsification or fabrication of test results, false statements in inspections	20 cases (2013–2021)
Cast Steel Products	Valve casing materials, Steam turbine casing materials	Falsification of inspection results, test results and analysis values	12 cases (2007–2022)
Forged Steel Products	Rolls, Forged steel pipes	Falsification or fabrication of inspection results, test results and analysis values	68 cases (2003–2020)
Steel Plate and Pipe Products	Stainless clad steel plate	Falsification of inspection results and analysis values	2 cases (2017, 2020)
Ordnance Product [(b)]	Forged steel materials	Falsification of test results and analysis values	6 cases (2020)

Source: Japan Steel Works, 2023[345]

Original notes by Japan Steel Works:

(a) Most of the cases were emergency measures that were triggered by sudden events that occurred in the manufacturing process, a finding that was confirmed in the investigation report by the Special Investigation Committee. There were circumstances that would not have otherwise been a problem if they had been reported to or discussed with the customers, but they were covered up without reporting to or discussing about with the customers, which constitutes a deviation from the procedural specifications sought by customers.

(b) There was no deviation from the specifications agreed on with final customers, but instead from the internal control values of M&E, whose customer is our Company (Hiroshima Plant).

New Energy Policy and the Role of Nuclear Energy

As reported in WNISR2022, in July 2022, Prime Minister Kishida's government expressed its intention to promote nuclear energy, while the detail of new policy was not known at that time.[346] On 10 February 2023, the Cabinet of PM Kishida's government approved the so-called "Green Transformation Basic Policy" which includes various measures to promote nuclear energy.[347] The main stated policy objective is to realize the goal of "Carbon neutrality by 2050" with an investment roadmap for ¥150 trillion (more than US$1.1 trillion) of public-private financing over the next 10 years. One of the main new policies is to "maximize the utilization of nuclear power". This is the major change from current energy policy which says Japan will "reduce dependence on nuclear energy as much as possible". The new policy also emphasizes the unstable energy situation caused by the war in Ukraine. Securing a stable energy supply is thus mentioned as a major reason to promote nuclear energy.[348]

On 31 May 2023, Japan's parliament passed a bill, so-called "GX bundled bill" which includes amendment of Nuclear Reactor Regulation Law, Electricity Utility Industry Law and Atomic Energy Basic Law. Those three laws specify the main features of the new policy as follows:

345 - Ibidem.

346 - *Reuters*, "Japan PM Kishida: asked industry minister to have up to 9 nuclear reactors operational this winter", 15 July 2022, see https://www.reuters.com/business/energy/japan-pm-kishida-asked-industry-minister-have-up-9-nuclear-power-plants-2022-07-14/, accessed 27 July 2022.

347 - Prime Minister's Cabinet Office, "GX Jitsugen ni muketa Kihon Hoshin ~ Kongo 10 nen wo misueta ro-do mappu e", February 2023 (in Japanese), see https://www.meti.go.jp/press/2022/02/20230210002/20230210002_1.pdf, accessed 29 June 2023.

348 - Noriyuki Ishii, "Cabinet Approves Basic Policy Aimed at Implementing GX", Japan Atomic Industrial Forum, 13 February 2023, see https://www.jaif.or.jp/en/news/6350, accessed 29 June 2023.

→ Extension of the "licensing period" (generally 40 years and 60 years for exceptional cases) allowing operators to apply for an extension of "certain shutdown period due to 'non-technical' or 'unplanned' reasons" (through amendment of the Nuclear Regulation Law and Electric Utility Industry Law)

This has become one of the most controversial issues of the GX Basic Policy. The licensing-period limitation was introduced after the Fukushima accidents primarily for two reasons. One is the safety concern over the aging reactors as Fukushima Daiichi-1 was just 40 years old (it started commercial operation in 1971 and had been given a 10-year lifetime extension one month prior to its accidental destruction) and all six Fukushima Daiichi units started commercial operation in the 1970s. The other reason was to facilitate the nuclear phaseout policy.[349] It was argued that there is no scientific basis to determine the lifetime of reactors and thus METI and the utility industry would like to extend the operation period beyond 40 and 60 years from the beginning of power generation for the periods during which reactors were shut down for "unplanned" reasons (beyond regular inspection period due to non-technical reasons such as licensing activities or socio-political reasons). In 2020, Japanese utilities filed a similar request with NRA before, but NRA rejected their request saying in July 2020: "It is difficult to determine extension period based on scientific and technical reasons as safety assessment should be made considering conditions of reactor by reactor".[350]

However, on 5 October 2022, NRA accepted METI's proposal to amend the lifetime extension regulation. NRA chairman Shinsuke Yamanaka said at a press conference that "extending operational period is a matter of energy policy and NRA is not in a position to comment" quoting the same July 2020 statement[351]. On 21 December 2022, NRA decided on possible changes in safety regulation for lifetime extension, preempting the amendment made by METI.[352] On 14 February 2023, NRA voted to accept the amendment of the Nuclear Regulation Law to allow METI to give approval for the extension of the operating period. It was unusual for NRA to take a vote as typically decisions are made on a consensus basis. But this time, one of the Commissioners, Akira Ishiwatari opposed the revision, saying NRA has not yet specific regulations for an entire 60-year operational lifetime and it is not logical and very strange that the longer the NRA takes to conduct a rigorous inspection the longer the operating period of a reactor life will be, as the inspection outage would not be included in the lifetime calculation.[353] Another commissioner, Tomoyuki Sugiyama said he felt the discussion was "rushed" as a result of government pressure. But NRA chairman Shinsuke Yamanaka denied that NRA yielded to government pressure.[354] Then it was revealed that NRA staff and METI officials met privately

349 - Yasumitsu Nawata, "Genpatsu no '40 nen ru-ru to sono Kadai – Hairo to Unten Kikan Encho no Senbetsu Ga Susumu", *Rippo to Chosa*, *Legislation and Investigation*, No. 381, October 2016 (in Japanese), pp. 55–66, see https://www.sangiin.go.jp/japanese/annai/chousa/rippou_chousa/backnumber/2016pdf/20161003055.pdf, accessed 29 September 2023.

350 - NRA, "Untenkikan Encho Ninka no Shinsa to Choki Teishi Kikan Chu no Hatsuden yo Gensiro Shisetsu no Keinen Rekka to no Kankei ni Kansuru Kenkai", Nuclear Regulation Authority, 29 July 2020 (in Japanese), see https://www.nra.go.jp/data/000323916.pdf, accessed 29 September 2023.

351 - *Nihon Keizai Shimbun*, "Genpatsu Unten 60nen Cho, Keisansho ga Ho-seibi Kento, Kisei-i mo yonin shisei", 5 October 2022 (in Japanese), see https://www.nikkei.com/article/DGXZQOUA04A5T0U2A001C2000000/, accessed 2 August 2023.

352 - Eric Johnston, "Watchdog Oks new rules to allow Japan's nuclear plants to operate beyond 60 years", *The Japan Times*, 21 December 2022, see https://www.japantimes.co.jp/news/2022/12/21/national/nuclear-reactor-longer-life-span/, accessed 29 September 2023.

353 - *Jiji Press*, "Regulator votes for longer operating life for nuclear reactors", as published in *The Japan Times*, 14 February 2023, see https://www.japantimes.co.jp/news/2023/02/14/national/regulator-reactor-lifespan/, accessed 29 June 2023.

354 - Mari Yamaguchi, "Japan watchdog Oks new safety rules to extend reactor life", *The Associated Press*, 14 February 2023, see https://apnews.com/article/politics-fumio-kishida-japan-plants-4f9a6d06582d1966c9a58c3e2a60deaa, accessed 12 July 2023.

several times to discuss amendments of Nuclear Regulation Laws without consulting NRA commissioners or keeping any records.[355] This is apparently against rules No. 1 (Independence) and No. 3 (Openness and Transparency) of NRA's Guiding Principles.[356] But the law passed on 31 May 2023, and now the METI Minister can determine lifetime extensions based on the condition that the reactors will pass the NRA safety review. NRA will review the conditions of reactors at least every 10 years after 30 years of operation.[357]

- Clarification of government's responsibility to support:

  a) the utility industry to build and construct innovative advanced reactors;

  b) nuclear industry to maintain and strengthen industrial base;

  c) smooth operation of decommissioning and disposal of radioactive waste (through amendment of the Atomic Energy Basic Law).

This amendment to the Atomic Energy Basic Law has attracted attention as it is unusual to introduce specific policy measures into basic framework legislation. The Atomic Energy Basic Law was passed in 1955 and was treated like a "Constitution for Atomic Energy" as it stipulates three basic principles (Autonomous, Democratic, Open) as well as guarantees that atomic energy is used only for peaceful purposes. However, this amendment clarifies "Government Responsibility" to support promotion of nuclear energy such as: assist electric utility industry by making "institutional arrangements" for building new reactors when they face difficulties under liberalized-market conditions. Some experts claim the amendment is against the spirit of the Basic Law and may lead to unnecessary tax money spending as well as to the reemergence of the "safety myth".[358]

- Institutional enhancement for decommissioning and radioactive waste disposal (through amendment of the Reprocessing Fund Compulsory Contribution Law)

This is similar to the obligation established by the Reprocessing Fund Compulsory Contribution Law which requires nuclear utilities to contribute an annual reprocessing and MOX-fabrication fee for spent fuel generated. Now the nuclear utilities are required to contribute a certain fee to cover future decommissioning costs. The amended law also added decommissioning of commercial nuclear reactors to the missions of the Nuclear Reprocessing Organization (NURO).[359]

355 - Junya Iwai, "Keisansho to no Hikoukai Mendan, Genshiryoku Kiseicho de Wareru Hyoka" ["Secret meetings with METI, divided views on NRA"], *Nikkei*, 15 January 2023 (in Japanese), see https://www.nikkei.com/article/DGXZQOUA069OJ0W3A100C2000000/, accessed 29 June 2023.

356 - The No.1 of Guiding Principles (Independence) says: "Make decisions independently, based on the latest scientific and technological information, free from any external pressure or bias". No.3 of Guiding Principles (Openness and Transparency) says: "Ensure transparency and appropriate information disclosure and keep openness to all opinions and advices"; see NRA, "Nuclear Regulation Authority—Protect the Public and the Environment", Nuclear Regulation Authority, Undated, see https://www.nra.go.jp/data/000067218.pdf, accessed 4 August 2023.

357 - *Kyodo News*, "Japan enacts law for operating nuclear reactors beyond 60-yr limit", 31 May 2023, see https://english.kyodonews.net/news/2023/05/4e5e10940b30-japan-enacts-law-for-operating-nuclear-reactors-beyond-60-yr-limit.html, accessed 29 June 2023.

358 - Ryo Sasaki, "Genshiryoku Kihon Ho no Kaisei An wa 'Atarashii Anzenshinwa No Tane', Hogakusha ga Kataru Mondaiten" ["Amendment to the Atomic Energy Basic Law can lead to 'New Nuclear Safety Myth', problems suggested by a law scholar"], *The Asahi Shimbun*, 30 May 2023 (in Japanese), see https://digital.asahi.com/articles/ASR5Z663PR5ZULBH009.html?iref=pc_ss_date_article, accessed 12 August 2023.

359 - Hideyuki Ban, "GX Bundled Bill: Attempts to Revive Nuclear Power Becoming More Obvious, Laws to be Equivocal", Citizens' Nuclear Information Center, 6 March 2023, see https://cnic.jp/english/?p=6531, accessed 29 June 2023.

In response to the first passage of the "GX Bundled Bill", several civil society organizations have raised their voices against the bill. For example, Citizens' Nuclear Information Center (CNIC), one of the leading anti-nuclear organizations, issued a statement on 28 April 2023, entitled "GX Nuclear Power Plant Bill Passed by Japanese House of Representatives After Diet Deliberations Full of Deceit and Fabrication".[360] Another leading civil society platform, the Citizens' Commission on Nuclear Energy (CCNE), also initiated a campaign to oppose the GX Bill calling for signatures from researchers and experts on this issue with 21 experts supporting the "emergency appeal" and hundreds of individuals and experts joining the campaign.[361]

Prospects for Nuclear Power

The new nuclear energy policies introduced under the GX Transformation laws represent a major shift as they allow for the construction of new reactors in Japan for the first time since the Fukushima disaster. It also amends the nuclear regulation laws to allow for lifetime extensions beyond 60 years. These new policies, which aim to maximize the use of nuclear power, are in fact inconsistent with the policy to reduce dependence of nuclear power as much as possible as stated in the current Energy Basic Plan.

A recent public-opinion survey suggests that support for the restart of existing reactors exceeds opposition to restarts for the first time since 3/11.[362] However, at least in the short term, it remains unclear how these new policies would change the conditions for utilities to restart reactors, and it is even less certain what the impact on the potential construction of new reactors could be. In addition, many issues associated with the decommissioning of the Fukushima Daiichi reactors remain unresolved (see Fukushima Status Report). Also, legal cases against reactor restarts and in favor of compensation for the impact of the Fukushima disaster continue. In short, the future of nuclear power in Japan is still far from certain.

POLAND FOCUS

Poland planned the development of several nuclear power stations in the 1980s and started construction of two VVER1000/320 reactors in Żarnowiec on the Baltic coast, but both construction and further plans were halted following the Chernobyl accident in 1986.[363] Since then, there has been a long, expensive, and time-consuming series of attempts to restart the program.

360 - CNIC, "CNIC Statement: GX Nuclear Power Plant Bill Passed by Japanese House of Representatives After Diet Deliberations Full of Deceit and Fabrication", Citizens' Nuclear Information Center, 27 April 2023, see https://cnic.jp/english/?p=6640, accessed 4 August 2023.

361 - CCNE, "GX Datsu Tanso Dengen Hoan ('Gensiryoku Sangyo Kyusai Hoan') No Seiritsu wo Yurusanai" ["We will not allow passage of GX Decarbonization Bill [Nuclear Industry Salvation Bill]", Campaign for Researcher/Experts' Emergency Appeal, Citizens' Commission on Nuclear Energy, 17 April 2023 (in Japanese), see http://www.ccnejapan.com/?p=13422, accessed 4 August 2023.

362 - *The Asahi Shimbun*, "Genpatsu Saikado, Sanse 51%, Shinsaigo Hajimete Sanpiga Gyakuten, Aashi Shimbun Yoron Chosa" ["Opinions supporting restart of nuclear reactors is 51%, exceeding opposition for the first time since the accident"], 20 February 2023, see https://digital.asahi.com/articles/ASR2M7V76R2MUZPS003.html, accessed 29 June 2023.

363 - Council of Ministers, "Uchwała nr 204 Rady Ministrów z dnia 17 grudnia 1990 r. w sprawie postawienia inwestycji Elektrownia Jądrowa 'Żarnowiec' w budowie w stan likwidacji.", Government of Poland, 17 December 1990 (in Polish), see https://isap.sejm.gov.pl/isap.nsf/download.xsp/WMP19900490373/O/M19900373.pdf, accessed 1 August 2023.

Once again, in 2008, Poland announced that it was going to re-enter the nuclear arena.[364] The Council of Ministers adopted a resolution providing for the development of a nuclear power program in January 2009, and the "Polish Energy Policy until 2030" in November 2009, which set a roadmap for the inclusion of nuclear to the country's energy infrastructure. The policy assumed that by 2030 three units (4.8 GW) would generate "over 10 percent" of the country's electricity, with the first unit put into operation "no[t] sooner than in 2020".[365] The following years saw negotiations with potential vendors, successive revisions of the project, various announcements, and delayed decisions (see past WNISR editions).

On 28 January 2014, the Polish Government adopted the "Polish Nuclear Power Programme" outlining the framework of the strategy. The plan included proposals to build 6 GW of nuclear power capacity at an estimated cost of PLN40–60 billion (US$$_{2014}$12.6–19 billion), with the first reactor starting up by 2024 and two units operating by 2035. A first site was to be named by 2016.[366] That did not happen.

Prior to the Government's 2014 strategy publication, state-owned utility Polska Grupa Energetyczn (PGE) had followed earlier attempts by declaring plans to build two nuclear power reactors in 2009. By February 2012, PGE's supervisory board ratified a strategy plan for 2012 to 2035 that included the construction of two reactors with a total capacity of 3 GW, with the first envisioned to be operational by 2025. Together with two other state-owned utilities Tauron Polska Energia and Enea, in cooperation with copper supply company KGHM Polska Miedz, PGE had agreed in 2013 on the supply of shares of PGE EJ1, a subsidiary of PGE that had been set up for the construction and operation of a potential new plant.[367]

In March 2017, PGE EJ1 launched site selection studies at Lubiatowo-Kopalino and Zarnowiec, both locations are close to the Baltic coast in the northern province of Pomerania.[368] A year later, rumors circulated on PGE corporation's declining interest in nuclear development as the company had supposedly shifted its attention towards offshore wind farms.[369] Nonetheless, the push for a nuclear strategy continued, and in November 2018, the Government published a draft strategic energy development program, which called for the construction of up to four reactors (providing 4–6 GW of capacity) by 2040, with the first in operation by 2033, and up to a total of six units with a combined capacity of 6–9 GW to be put into operation by 2043.[370] In

364 - *WNN*, "Poland looks to nuclear to replace coal", with *Bloomberg* and *AFP*, 1 December 2023, see https://www.world-nuclear-news.org/Articles/Poland-looks-to-nuclear-to-replace-coal, accessed 1 August 2023.

365 - Ministry of Economy, "Energy Policy of Poland until 2030", adopted by the Council of Ministers, Government of Poland, 10 November 2009.

366 - Ministerstwo Gospodarki, "Polish Nuclear Power Programme", Ministry of Economic Affairs, Government of Poland, January 2014, see https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Umweltpruefungen/polnische_kernenergie_programm_en_bf.pdf; and *The Economist*, "Going Nuclear", 31 January 2014, see https://www.economist.com/eastern-approaches/2014/01/31/going-nuclear; both accessed 1 August 2023.

367 - *WNN*, "Polish cabinet approves new nuclear plan", *World Nuclear News*, 29 January 2014, see https://www.world-nuclear-news.org/Articles/Polish-cabinet-approves-new-nuclear-plan, accessed 23 August 2023.

368 - *NEI Magazine*, "Site Studies begin for Poland's first NPP", *Nuclear Engineering International*, 12 April 2017, see https://www.neimagazine.com/news/newssite-studies-begin-for-polands-first-npp-5784946/, accessed 1 August 2023.

369 - Agnieszka Barteczko and Pawel Goraj, "Exclusive: PGE picks Baltic wind over nuclear as Poland embraces green power", *Reuters*, 10 May 2018, see https://www.reuters.com/article/us-poland-energy/exclusive-pge-picks-baltic-wind-over-nuclear-as-poland-embraces-green-power-idUSKBN1IB0LE, accessed 10 May 2018.

370 - Gary Peach, "Newbuild: Power Demand in Poland Bolsters Case for Nuclear", *Nuclear Intelligence Weekly*, 26 November 2018; and *WNN*, "Poland sets financing target for nuclear plant", *World Nuclear News*, 19 November 2019, see https://www.world-nuclear-news.org/Articles/Poland-sets-financing-target-for-nuclear-plant, accessed 1 May 2021.

May 2019, the Ministry of Energy envisaged the site selection for the first plant in 2020, while the technology would be chosen in 2021.[371]

In October 2020, the Council of Ministers adopted a revised long-term Polish Nuclear Power Program.[372] It maintains the objective to build and commission nuclear power plants in Poland with a total installed capacity of approximately 6–9 GW based on Generation III (+) pressurized water reactors, with the start of operation during the 2030s, while the share of nuclear power in the electricity mix is predicted to reach about 20 percent by 2045. According to the documentation, the timetable was as follows:

- **2021**: choice of technology for the first (EJ1) and second plant (EJ2);
- **2022**: site license for EJ1;
- **2026**: building permit and construction start of EJ1;
- **2028**: site license for EJ2;
- **2032**: building permit and construction start of EJ2;
- **2033–2037**: operating license by the President of the National Atomic Energy Agency (PAA) and commissioning of three units (EJ1);
- **2038–2043**: operating license by President of PAA, and commissioning of three units (EJ2).[373]

In the same month, the U.S. and Polish governments signed an agreement on the "cooperation towards the development of a civil nuclear power program and the civil nuclear power sector in [...] Poland". The agreement includes cooperation plans on the development of financing regulations and schemes, technological knowledge transfer, and the "development, construction, and financing of the first [nuclear power plant] project, intended to be operational during 2033." The agreement came into force in February 2021.[374] In June 2021, a first grant was issued by the U.S. Trade and Development Agency to fund a front-end engineering and design study for Polskie Elektrownie Jądrowe (PEJ).[375]

PEJ is the direct descendant of PGE EJ1. In March 2021, the four owners PGE (70 percent of shares), Enea, Tauron and KGHM (10 percent each) had sold ownership to the Polish State Treasury "in preparation for reali[z]ation of the Polish nuclear power [program]". Negotiations had begun in October 2020, and the transaction cost the Treasury around

371 - *WNN*, "Poland already preparing for nuclear plant, says energy minister", *World Nuclear News*, 16 May 2019, see https://www.world-nuclear-news.org/Articles/Poland-already-preparing-for-nuclear-plant,-says-e, accessed 1 May 2021.

372 - Republic of Poland, "Polish Nuclear Power Programme", adopted 2 October 2020, promulgated 16 October 2020, see https://www.gov.pl/attachment/4cddd10a-5e8b-414d-bb95-670f6507d73e, accessed 1 August 2023.

373 - Ibidem.

374 - Government of the United States of America and Government of the Republic of Poland, "Agreement Between the Government of the United States of America and the Government of the Republic of Poland on Cooperation Towards the Development of a Civil Nuclear Power Program and the Civil Nuclear Power Sector in the Republic of Poland", Signed on 19 and 22 October 2020, Enforced 24 February 2021, U.S. Department of State, see https://www.state.gov/wp-content/uploads/2021/05/21-224-Poland-Nuclear-Energy.pdf, accessed 23 August 2023.

375 - U.S. Trade and Development Agency, "USTDA Advances Poland's Civil Nuclear Energy Program by Funding U.S. Industry-Led Study", Press Release, 30 June 2021, see https://www.ustda.gov/ustda-advances-polands-civil-nuclear-energy-program-by-funding-u-s-industry-led-study/, accessed 7 November 2023.

PLN531 million (US$$_{2021}$137.5 million).[376] In June 2021, "PGE EJ1" was renamed "Polskie Elektrownie Jądrowe", or "PEJ".[377]

In late December 2021, PEJ announced it had chosen the village of Choczewo in Pomerania for the first reactor.[378] In March 2022, PEJ submitted the Environmental Impact Assessment report for the project.[379]

Reportedly, the actual offers submitted between October 2021 and September 2022 included the plans of Korea Hydro & Nuclear Power (KHNP) for six APR-1400 (8.4 GW) for US$26.7 billion, Westinghouse's proposal to build six AP-1000 (6.7 GW) for US$31.3 billion, and EDF's preliminary offer of four to six EPRs (6.6–9.9 GW) for US$33–48.5 billion.[380]

In May 2022, KHNP Deputy CEO Lim Seung-yeol told the *Polish Press Agency*, the company would envisage taking a 20–30-percent equity stake in the newbuild project, which "would be [...] KHNP's direct contribution to the investment. The rest would be covered by financial institutions. On the Korean side, it would be export credit-agencies."[381] It remains unclear whether the offer to inject capital would cover the first three units only or the entire package of up to six APR-1400. In any case, the Korean initiative represented a financing offer that would be difficult to match for EDF or Westinghouse.

Regardless, in November 2022, Westinghouse was formally appointed as the contractor to deliver three reactors to the Pomeranian project at costs of around US$20 billion.[382] In January and September 2022, Westinghouse had already signed MoUs with 10 then 22 Polish supply companies, for cooperation on various potential tasks such as steel manufacturing, translation services and machine maintenance.[383] Given that KHNP's initial offer was cheaper by several billion US$, it is understood that the decision is of a more geopolitical nature, i.e. to strengthen ties between the governments of Poland and the U.S.[384] However, as discussed below, South Korean actors might come to build nuclear reactors in Poland after all. Opposition to the project

376 - *NEI Magazine*, "Polish state takes over nuclear company in preparation for NPP construction", 30 March 2021, see https://www.neimagazine.com/news/newspolish-state-takes-over-nuclear-company-in-preparation-for-npp-construction-8635299, accessed 23 August 2023.

377 - PEJ, "New company name: Polskie Elektrownie Jądrowe sp. z o.o.", Press Release, Polskie Elektrownie Jądrowe, 7 July 2021, see https://ppej.pl/en/news/new-company-name-polskie-elektrownie-jadrowe-sp.-z-o.o, accessed 23 August 2023.

378 - *NEI Magazine*, "Poland selects site for first nuclear power plant", 30 December 2021, see https://www.neimagazine.com/news/newspoland-selects-site-for-first-nuclear-power-plant-9354373, accessed 31 August 2022.

379 - PEJ, "Environment Impact Assessment Report", Polskie Elektrownie Jądrowe, May 2022, see https://ppej.pl/en/environment-and-consultations/environmental-impact-assessment-report, accessed 1 August 2023.

380 - *NEI Magazine*, "Westinghouse and KHNP may both build NPPs in Poland", *Nuclear Engineering International*, 3 November 2022, see https://www.neimagazine.com/news/newswestinghouse-and-khnp-may-both-build-npps-in-poland-10144809, accessed 1 August 2023.

381 - Phil Chaffee, "Newbuild: KHNP Jolts Competitors With Equity Stake Appetite", *Nuclear Intelligence Weekly*, 3 June 2022, see https://www.energyintel.com/00000181-2018-d67b-a3cd-f4da7e5a0000, accessed 1 August 2023.

382 - Alan Charlish, Anna Wlodarczak-Semczuk, Anna Koper and Marek Strzelecki, "Poland's first nuclear power plant to cost around $20 bln - PM", *Reuters*, 2 November 2022, see https://www.reuters.com/business/energy/polands-first-nuclear-power-station-cost-around-20-bln-says-pm-2022-11-02/; and Prime Minister's Office, "Uchwała w sprawie budowy wielkoskalowych elektrowni jądrowych w Rzeczypospolitej Polskiej", Press Release (in Polish), Government of Poland, 2 November 2022, see https://www.gov.pl/web/premier/uchwala-w-sprawie-budowy-wielkoskalowych-elektrowni-jadrowych-w-rzeczypospolitej-polskiej; both accessed 1 August 2023.

383 - Westinghouse, "Westinghouse Signs Strategic Partnerships in Poland to Build Country's First AP1000® Nuclear Plant", Press Release, 21 January 2022, see https://info.westinghousenuclear.com/news/westinghouse-strategic-partnerships-poland; and Westinghouse, "Westinghouse Establishes Cooperation with Dozens of Polish Suppliers for the Construction of the First Polish Nuclear Power Plant", Press Release, 22 September 2022, see https://info.westinghousenuclear.com/news/wec-establishes-cooperation-with-polish-suppliers; both accessed 24 August 2023.

384 - *NEI Magazine*, "Westinghouse and KHNP May Both Build NPPs in Poland", op. cit.

was voiced by four East German states (Brandenburg, Saxony, Mecklenburg-Vorpommern, and Berlin) during the consultation period of the environmental impact assessment process.[385] Nonetheless, cooperation agreements were signed between Westinghouse and PEJ in December 2022.[386] These were further advanced when in February 2023, a contract covering front-end engineering, early procurement work and program development was signed between Westinghouse and PEJ,[387] followed in May 2023 by an agreement "defining the principles of the parties' [Westinghouse, PEJ and Bechtel] cooperation in the design and construction of Poland's first nuclear power plant."[388] On 13 April 2023, PEJ had applied to the Ministry of Climate for a "decision-in-principle" on the project,[389] which was granted in July 2023, allowing for further administrative applications to proceed.[390] At this stage, construction work is planned to begin in 2026, with electricity generation to commence in 2033.[391]

In parallel, in a notable development, in October 2022, Polish utility Zespół Elektrowni Pątnów-Adamów-Konin (ZE PAK) and PGE as well as KHNP signed a letter of intent to develop plans for a second nuclear power plant based on KHNP's APR-1400 technology in Pątnów, central Poland, at the site of a lignite power plant. On the same day, Poland's Minister of Assets, the Deputy Prime Minister, and South Korea's Minister of Trade, Industry and Energy also signed a Memorandum of Understanding (MoU) "to support the nuclear energy project in Patnow [Pątnów] and tighten cooperation in the scope of necessary information exchange". This nuclear plant would constitute the second phase of the 6–9 GW nuclear capacity envisioned in Poland's Nuclear Power Program from 2021.[392] The project however might come under E.U. investigation due to possible noncompliance with competition regulation that requires multiple equally treated bidders to be allowed to compete for such large infrastructure projects.[393] Regardless, ZE PAK and PGE announced in March 2023 they would establish a joint venture to "represent the Polish side at all stages of the [Pątnów] project", now planned with

385 - MSGIV, "Geplantes Kernkraftwerk in Polen: Einwände auch aus Brandenburg", Press Release Nr 538/2022 (in German), Ministerium für Soziales, Gesundheit, Integration und Verbraucherschutz Brandenburg/Ministry for Social Issues, Health, Integration and Consumer Protection of Brandenburg, 13 December 2022, see https://msgiv.brandenburg.de/sixcms/media.php/9/538_22_MSGIV_Einwaende_KKW_Polen_20221213.pdf, accessed 1 August 2023.

386 - *WNN*, "Westinghouse and Poland's PEJ sign agreement on AP1000 'next steps'", *World Nuclear News*, 16 December 2022, see https://www.world-nuclear-news.org/Articles/Westinghouse-and-Polands-PEJ-sign-AP1000-reactor, accessed 1 August 2023.

387 - Westinghouse, "Westinghouse and Polskie Elektrownie Jądrowe Advance Poland's Nuclear Energy Program with Contract Signing", Press Release, 22 February 2023, see https://info.westinghousenuclear.com/news/wec-pej-poland-contract-signing, accessed 1 August 2023.

388 - Westinghouse, "Westinghouse and Bechtel Solidify Project Team for AP1000® Nuclear Power Program in Poland", Press Release, 25 May 2023, see https://info.westinghousenuclear.com/news/westinghouse-and-bechtel-solidify-project-team-for-ap1000-nuclear-power-program-in-poland, accessed 1 August 2023.

389 - PEJ, "Polskie Elektrownie Jądrowe company submits an application for a decision-in-principle for the first Polish nuclear power plant", Press Release, Polskie Elektrownie Jądrowe, 13 April 2023, see https://ppej.pl/en/news/polskie-elektrownie-jadrowe-company-submits-an-application-for-a-decision-in-principle-for-the-first-polish-nuclear-power-plant, accessed 1 August 2023.

390 - PEJ, "The Polskie Elektrownie Jądrowe company with a decision-in-principle for the first nuclear power plant in Poland", Press Release, Polskie Elektrownie Jądrowe, 12 July 2023.

391 - Sonal Patel, "Westinghouse, Bechtel Form Consortium to Design and Build Poland's First Nuclear Plant", *POWER Magazine*, 25 May 2023, see https://www.powermag.com/westinghouse-bechtel-form-consortium-to-design-and-build-polands-first-nuclear-plant/, accessed 6 June 2023.

392 - *WNN*, "South Korea's KHNP signs letter of intent on Polish nuclear", *World Nuclear News*, 31 October 2022, see https://www.world-nuclear-news.org/Articles/South-Korea-s-KHNP-signs-letter-of-intent-on-Polis, accessed 1 August 2023.

393 - WNA, "Nuclear Power in Poland", World Nuclear Association, Updated May 2023, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/poland.aspx, accessed 6 June 2023.

at least two APR-1400 reactors delivered by KHNP, scheduled to be on the grid by 2035.[394] This joint-venture, named PGE PAJ Energia Jądrowa, was established with a 50/50 share by both companies in April, and in August 2023, submitted an application to the Polish Ministry of Climate for a "decision-in-principle" on the construction of a nuclear power plant consisting of two APR-1400 reactors.[395] In the meantime, South Korean and Polish firms signed six MoUs relating to nuclear generation at the Korea-Poland Business Forum held in Warsaw in July 2023. Two of those were signed between Doosan Enerbility and Polish companies on the construction of nuclear power plants in Poland.[396]

In an attempt to block KHNP's participation in the competition (and possibly hinder KHNP's further expansion to other Eastern European Countries, e.g., the Czech Republic) Westinghouse filed a lawsuit against KHNP and its owner Korea Electric Power Corp. (KEPCO) before the U.S. Federal Court in October 2022.[397] Westinghouse argues that KHNP is infringing on intellectual property rights owned by Westinghouse regarding "System 80 reactor technology" that were originally held by Combustion Engineering, a company that was taken over by Westinghouse in 2000.[398] Arguably, KHNP would require permission to export this technology, to which KHNP states that all necessary regulations had been followed.[399] An attempt to settle the decades-old dispute outside of judiciary was made in January 2023 by KHNP and KEPCO by suggesting a split of potential profits of a nuclear project with Westinghouse.[400] The parties had until 17 March 2023 to come to some form of agreement which did not happen.[401] The Korean Commercial Arbitration Board begun assessing damages claimed by both sides, possibly amounting to several hundred million US$, in August 2023.[402]

In addition to negotiations around potential orders of large reactors, Poland eyes the possibility of investing in Small Modular Reactors (SMRs). Various cooperation agreements have been signed including between the Polish state-owned company Enea S.A. and U.S. SMR developer

394 - *WNN*, "Joint company launched to implement Pątnów project", *World Nuclear News*, 8 March 2023, see https://www.world-nuclear-news.org/Articles/Joint-company-launched-to-implement-Patnow-project; and ZEPAK, "PGE and ZE PAK will establish a company to implement a nuclear power plant construction project", 8 March 2023, see https://www.zepak.com.pl/en/about-us/press-office/news/14521-pge-and-ze-pak-will-establish-a-company-to-implement-a-nuclear-power-plant-construction-project.html; both accessed 6 June 2023.

395 - *WNN*, "Approval sought for second large Polish nuclear power plant", *World Nuclear News*, 17 August 2023, see https://www.world-nuclear-news.org/Articles/Approval-sought-for-second-large-Polish-nuclear-po, accessed 24 August 2023.

396 - *WNN*, "South Korea and Poland enhance cooperation in nuclear", 14 July 2023, see https://world-nuclear-news.org/Articles/South-Korea-and-Poland-enhance-cooperation-in-nucl, accessed 24 August 2023.

397 - *NEI Magazine*, "Westinghouse tries to exclude South Korea from Poland's NPP project", 27 October 2022, see https://www.neimagazine.com/news/newswestinghouse-tries-to-exclude-south-korea-from-polands-npp-project-10122581, accessed 2 May 2023.

398 - *NEI Magazine*, "BNFL buys ABB's nuclear business", 28 January 2000, see https://www.neimagazine.com/news/newsbnfl-buys-abb-s-nuclear-business, accessed 1 August 2023.

399 - Jessica Sondgeroth, "Newbuild: Dispute Unresolved on Eve of Washington-Seoul Summit", *Energy Intelligence*, 14 April 2023, see https://www.energyintel.com/00000187-7bf7-dc4f-a7e7-7bf7b6b50000, accessed 6 June 2023.

400 - *NEI Magazine*, "South Korea seeks to end dispute with Westinghouse", 12 January 2023, see https://www.neimagazine.com/news/newssouth-korea-seeks-to-end-dispute-with-westinghouse-10511335, accessed 23 August 2023.

401 - Westinghouse Electric Company, and Korea Electric Power Corp. and Korea Hydro & Nuclear Power Co., Ltd., "Joint Motion to Stay Proceedings Pending Settlement Negotiations", Case No. 1:22-cv-03228-APM, U.S. District Court for the District of Columbia, filed 10 January 2023, as released on *Jus Mundi*, see https://jusmundi.com/en/document/pdf/other/en-korea-hydro-nuclear-power-co-ltd-and-korea-electric-power-corporation-v-westinghouse-electric-company-llc-joint-motion-to-stay-proceedings-pending-settlement-negotiations-tuesday-10th-january-2023, accessed 7 November 2023; and *NEI Magazine*, "US stalls South Korea's NPP export plans", 11 April 2023, see https://www.neimagazine.com/news/newsus-stalls-south-koreas-npp-export-plans-10747925, accessed 23 August 2023.

402 - Jin-Seong Kim and Han-Shin Park, "Westinghouse, KHNP seek licensing dispute arbitration", *The Korea Economic Daily*, 2 August 2023, see https://www.kedglobal.com/energy/newsView/ked202308020008, accessed 29 August 2023.

Last Energy to cooperate on the deployment of SMRs.[403] In April 2023, the U.S. Export-Import Bank and the U.S. International Development Finance Corporation both signed letters of interest to provide loans, up to US$3 billion and US$1 billion respectively, to the Orlen Synthos Green Energy (OSGE) project.[404] The project emerged in March 2022, when PKN Orlen, Poland's largest oil company, joined forces with Synthos Green Energy to "invest in the development of micro and small modular reactor technologies".[405] In March 2023, GE Hitachi (GEH), Tennessee Valley Authority (TVA), Ontario Power Generation (OPG) and OSGE agreed to collaborate on the global development of the GEH BWRX-300 reactor. In June 2023, OPG and OSGE separately signed a letter of intent to cooperate on various SMR-related activities.[406] The project envisions the construction of up to 20 BWRX-300 reactors in Poland, with launch of the first one expected in 2029.[407]

Polish efforts to become a country operating commercial nuclear power plants have intensified over the past several years. The planned parallel implementation of three different technologies (Westinghouse's AP-1000, KHNP's APR-1400 and SMRs) in a country that has only little experience in the construction of nuclear power plants (dating back four decades), their operation, and the regulation thereof seems ambitious.[408] Whether Poland will be able to pull off these plans, especially given that many details on contracts and financing remain undisclosed, remains uncertain.

The Polish electricity mix is highly dependent on coal, which contributed 69 percent to the electricity mix in 2022, followed by wind (11 percent), natural gas (7 percent), and solar (4.5 percent). The remainder is generated from various other fossil and renewable sources such as bioenergy and hydro.[409]

The extension of onshore wind capacities ceased in 2016 when restrictive distance laws ("10H legislation") essentially brought onshore newbuild to a standstill. By 2022, only a total of about 8.3 GW had been installed. A 2022-amendment of the law might foster some project development, while the Government's target lies at only 14 GW by 2030 and 20 GW by 2040. The first offshore wind farm is expected to come online in 2026, and a total of 12 GW of offshore capacity is planned.[410]

In comparison, solar energy is rapidly gaining significance. Over the course of 2022, solar capacity grew from 7.7 GW in 2021, to 12.4 GW, a 61 percent increase. For context, in 2019,

403 - *WNN*, "Poland expands cooperation on SMRs and large reactors", *World Nuclear News*, 23 June 2022, see https://www.world-nuclear-news.org/Articles/Poland-expands-cooperation-on-SMRs-and-large-react, accessed 23 June 2022.

404 - Monika Scislowska, "US ready to lend Poland $4 billion for nuclear energy plan", *The Associated Press*, 17 April 2023, see https://apnews.com/article/nuclear-energy-us-poland-221e7fcbe13bba60bd872929a9c822aa, accessed 2 August 2023.

405 - PKN Orlen, "PKN Orlen steps up work on nuclear technology", 7 March 2022, see https://www.orlen.pl/en/about-the-company/media/press-releases/2022/march-2022/PKN-ORLEN-steps-up-work-on-nuclear-technology, accessed 7 June 2023.

406 - *WNN*, "OPG and OSGE enhance cooperation on SMRs", *World Nuclear News*, 5 June 2023, see https://www.world-nuclear-news.org/Articles/OPG-and-OSGE-enhance-cooperation-on-SMRs, accessed 2 August 2023.

407 - Monika Scislowska, "US Ready to Lend Poland $4 Billion for Nuclear Energy Plan", *The Associated Press*, April 2023, op. cit.

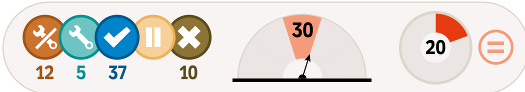
408 - Poland has been operating a single 30 MW research reactor since 1974; see NCBJ, "The MARIA research reactor", Narodowe Centrum Badań Jądrowych/National Centre for Nuclear Research, Undated, see https://www.ncbj.gov.pl/en/o-nas/maria-research-reactor, accessed 24 August 2023.

409 - Ember, "Ember Electricity Data Explorer—Poland electricity generation by source", 2023, see https://ember-climate.org/data/data-tools/data-explorer/, accessed 23 August 2023.

410 - Polish Wind Energy Association, TPA Poland, Baker Tilly Poland and DWF, "Wind Energy in Poland 2023", May 2023, see http://psew.pl/wp-content/uploads/2023/06/Energetyka-wiatrowa-w-Polsce_2023_internet.pdf, accessed 24 August 2023.

solar generation accounted for only 0.4 percent of Polish electricity, an 11-fold increase of the solar share in three years. Provisional announcements of updates to the Polish Energy Strategy envision a total of 27 GW to be installed by 2030.[411]

RUSSIA FOCUS



In 2022, nuclear energy contributed 20 percent to the country's electricity mix, with another record production of 209.5 TWh, up from 208.5 TWh in 2021. 2022 did not see the startup or closure of any reactors, and as of mid-2023, 37 reactors were operating, and ten have been permanently closed.

There are five reactors under construction in or for Russia, including two barges built in China but destined to Russia. Two are large units at Kursk II, a significant project, as it involves the first of the latest Russian design, the VVER-TOI (VVER-V-510), officially expected to cost around US$3.5 billion, although this is likely to be a significant underestimate.[412] These are 1200 MW, Generation III+ design, and are also earmarked for export. When construction started on Unit 1, project completion was scheduled for late 2023, and in April 2020, the first deputy director for construction claimed that the project was on schedule.[413] In November 2022, plant director Alexander Uvakin was quoted as saying "We hope that 2024-2025 will see the physical start-up and commercial operation of the first and then the second unit of the Kursk-II NPP".[414] While no completion date has been confirmed, in July 2023, Rosatom announced that the last structural element was installed, and therefore, completion is likely to be some way off.[415] In February 2023, public hearings began on the planned building of Units 3 and 4.[416]

Construction of an innovative SMR fast reactor design using liquid lead as a coolant and uranium-plutonium nitride for fuel started in June 2021. The objective for the BREST-OD-300 reactor is for it to operate by 2026, and it is said to cost 100 billion rubles (US$$_{2021}$1.4 billion).[417] In June 2020, Rosenergoatom announced that preparation work would begin for the construction of four new reactors, Units 3 and 4 at Leningrad II (also referred to as Leningrad-II NPP Units 7 and 8 when including the previous four RMBK reactors), as well as two reactors at Smolensk II.[418] In December 2022, concrete was poured for the first buildings for the new units at Leningrad, which are due to be completed at the end of 2023,

411 - IEO, "Photovoltaic Market in Poland 2023 - Summary", Instytut Energetyki Odnawialnej/Institute for Renewable Energy, 2023, see https://ieo.pl/en/pv-report/pv-report-2023, accessed 21 July 2023.

412 - *Power Technology*, "Kursk II Nuclear Power Plant", 5 June 2023, see https://www.power-technology.com/projects/kursk-ii-nuclear-power-plant/, accessed 16 July 2023.

413 - *NEI Magazine*, "Russia's Kursk II on schedule", *Nuclear Engineering International*, 14 April 2020, see https://www.neimagazine.com/news/newsrussias-kursk-ii-on-schedule-7872033/, accessed 10 April 2021.

414 - *NEI Magazine*, "Russia's Kursk unit 2 to be permanently closed in 2024", *Nuclear Engineering International*, 9 November 2022, see https://www.neimagazine.com/news/newsrussias-kursk-unit-2-to-be-permanently-closed-in-2024-10280637, accessed 3 June 2023.

415 - *NEI Magazine*, "Test assembly of VVER-1200 reactor completed at Kursk-II unit 1", *Nuclear Engineering International*, 12 July 2023, see https://www.neimagazine.com/news/newstest-assembly-of-vver-1200-reactor-completed-at-kursk-ii-unit-1-11000538/, accessed 16 July 2023.

416 - *NEI Magazine*, "Public hearings to begin on construction Kursk-II NPP units 3&4", 17 February 2023, see https://www.neimagazine.com/news/newspublic-hearings-to-begin-on-construction-kursk-ii-npp-units-34-10604904/, accessed 16 July 2023.

417 - Gary Peach, "Construction Starts on Lead-Cooled Fast Reactor", *Nuclear Intelligence Weekly*, 11 June 2021.

418 - *WNN*, "Russia begins preparatory work for four new reactors", *World Nuclear News*, 26 June 2020, see https://www.world-nuclear-news.org/Articles/Russia-begins-preparatory-work-for-four-new-reacto, accessed 16 July 2023.

after which formal construction on Unit 7 could begin in 2024.[419] It is unlikely that they will begin generating electricity this decade. The last reactor to start up in Russia, Leningrad 2-2 in 2020, took 10.5 years to build.

In August 2022, Rosatom announced the keel-laying ceremony—considered construction start for floating reactors—in China of the first Arctic-type Nuclear Floating Power Unit (NFPU) to be equipped with two RITM-200C reactors and to be deployed in Russia, in the framework of the Cape Nagloynyn project.[420]

In March 2021, in its strategic review, Rosatom said that by 2045, nuclear energy should provide 25 percent of the country's electricity. According to Rosatom CEO Alexei Likhachev, this will require the commissioning of 24 blocks, including at new sites and in new regions.[421] Rosatom reiterated its intentions in May 2022. The list of sixteen new reactors in the plan for 2035 includes:

- Kursk-II: Units 1–4; Leningrad-II: Units 3 & 4 (VVER-1200 reactors);
- Smolensk-II: Units 1 & 2 (VVER-TOI reactors);
- Baimsky GOK: four modernized FNPP units (RITM-200 reactors);
- Small reactor in Yakutia: Unit 1 (RITM-200 reactor);
- ODEK in Seversk: BREST-OD-300;
- Kola-II: Unit 1 (VVER-S or VVER-600 reactor);
- and Beloyarsk: Unit 5 (BN-1200M fast reactor),[422]

the majority of which will be at or close to existing nuclear power plant sites, although these include three new sites in Biamsky and Yakutia (in the far East), and the proposed Seversk facility in the Tomsk oblast, a closed city and site of military nuclear facilities.

Russia has closed ten power-generating reactors: Beloyarsk-1 and -2, Bilibino-1, Leningrad-1 and -2, Kursk-1, Novovoronezh-1–3, and Obninsk-1, with a further ten units to potentially close by 2030 without operating lifetime extensions.[423]

The average age of the Russian reactor fleet is 29.9 years as of mid-2023, with close to two-thirds being 31 years or more, of which 12 operated for 41 years or more (see Figure 43). Therefore, a vital issue for the industry is managing its aging units.

There are six classes of reactors in operation: the RBMK (a graphite-moderated reactor of the Chernobyl type), the VVER-440, the VVER-1000, the VVER-1200, the KLT-40 and FBRs.

419 - *NEI Magazine*, "Work begins on Leningrad-II NPP units 7&8", *Nuclear Engineering International*, 22 December 2022, see https://www.neimagazine.com/news/newswork-begins-on-leningrad-ii-npp-units-78-10456801, accessed 26 August 2023.

420 - Rosatom, "Keel-laying ceremony for the first Arctic-type Floating Power Unit with RITM-200 transport reactor vessels", Press Release, 30 August 2022, see https://rosatom-mena.com/press-centre/news/keel-laying-ceremony-for-the-first-arctic-type-floating-power-unit-with-ritm-200-transport-reactor-v/; and *WNN*, "Construction starts on Russia's next floating nuclear power plant", *World Nuclear News*, 31 August 2022, see https://www.world-nuclear-news.org/Articles/Construction-starts-on-Russia-s-next-floating-nucl, accessed 30 August 2023.

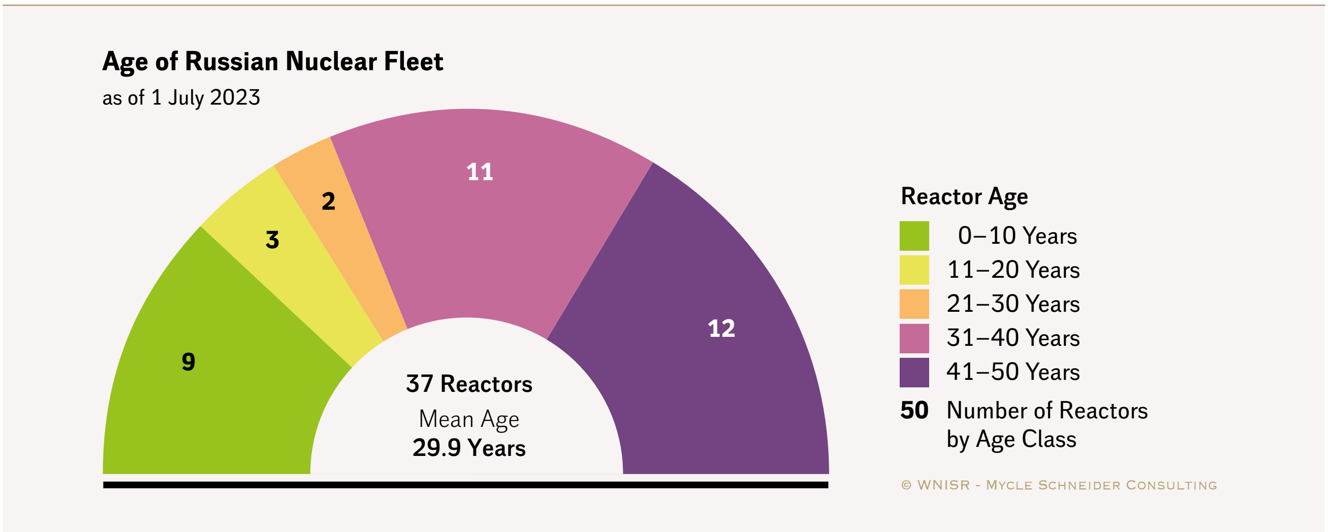
421 - *NEI Magazine*, "Rosatom's development plans", *Nuclear Engineering International*, 11 March 2021, see https://www.neimagazine.com/news/newsrosatoms-development-plans-8592063/, accessed 16 July 2023.

422 - *NEI Magazine*, "Russia to build 16 new nuclear units by 2035", *Nuclear Engineering International*, 1 June 2022, see https://www.neimagazine.com/news/newsrussia-to-build-16-new-nuclear-units-by-2035-9738009, accessed 16 July 2023.

423 - Ibidem.

Designed for an operational lifetime of 30 years, both the RBMKs and VVER-440 designs have been granted 15-year lifetime extensions to enable them to operate for 45 years. The process of annealing, whereby the reactor pressure vessel is heated for an extended period of time has been undertaken in VVER 440 reactors in Armenia, Bulgaria and Ukraine and is hoped to extend the operating life of the vessels until up to 60 years,[424] while the VVER-1000s are expected to work for up to 50 years. Consequently, the closure of Leningrad-1 and -2 after 45 years of operation, in 2018 and 2020 respectively, is potentially a significant event, as it could indicate that a 60-year operational lifetime is beyond the RMBK potential. The current operating licenses for Units 3 and 4 expire in 2025 and 2026 when they are likely to close.[425] At the same time, the RMBKs at Kursk are also closing after 45 years, with Unit 1 closed since 2021 and Unit 2 set to close in 2024.[426]

Figure 43 · Age Distribution of the Russian Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2023

The country also operates two Fast Breeder Reactors (FBRs) at Beloyarsk (Units 3 and 4). The older and smaller of the two reactors is a 600 MW unit, which was connected to the grid in 1980 with an expected operational lifetime of 30 years. This was extended for the second time in April 2020 for a further five years to enable the unit to operate until 2025, but plans are being developed to enable the unit to operate for 60 years.[427]. The new VVER-1200 reactors in Novovorenezh II and Leningrad II have a design lifetime of 60 years, with some studies said

424 - *NEI Magazine*, "Renewal by annealing", *Nuclear Engineering International*, 25 April 2019, see https://www.neimagazine.com/features/featurerenewal-by-annealing-7171272/, accessed 4 September 2023.

425 - *WNN*, "Leningrad 3's new licence", *World Nuclear News*, 10 December 2009, see https://www.world-nuclear-news.org/Articles/Leningrad-3-s-new-licence; and *WNN*, "Licence extension for Leningrad 4", 4 January 2011, see https://www.world-nuclear-news.org/Articles/Licence-extension-for-Leningrad-4; both accessed 26 August 2023.

426 - *NEI Magazine*, "Russia's Kursk unit 2 to be permanently closed in 2024", 9 November 2022, see https://www.neimagazine.com/news/newsrussias-kursk-unit-2-to-be-permanently-closed-in-2024-10280637, accessed 26 August 2023.

427 - *WNN*, "BN-600 licensed to operate until 2025", *World Nuclear News*, 1 April 2020, see https://www.world-nuclear-news.org/Articles/BN-600-licensed-to-operate-until-2025, accessed 1 April 2020.

to enable up to 100 years of operation for their pressure vessels. A new "ultra pure" nickel material would even allow for 120 years of irradiation of future vessels, Rosatom claims.[428]

Russia is an aggressive exporter of nuclear power, with, according to one report from Rosatom, 33 separate projects in various stages of advancement.[429] These claims must be taken with some skepticism, as the same source claims seven reactors are under construction domestically when, by most accounts, there are three, plus the two barges for floating reactors that are being built in China. As the reactors will be added to the barges in Russia and the plant is to operate in Russia, WNISR considers this as a domestic Russian project. As of 1 July 2023, Rosatom is involved as the main contractor of the following projects abroad in various stages of active construction:

- **Bangladesh** – Construction started on two reactors at Rooppur in 2017 and 2018, which were expected to begin operation in December 2023, but commissioning will not start before 2024 and more likely 2025.[430] See section on Bangladesh in Potential Newcomer Countries.
- **China** – Two reactors each at Tianwan and Xudabu (or Xudabao). Construction started for the respective first units in 2021 for the respective second units in 2022.[431] See China Focus.
- **Egypt** – Three reactors are under construction at El Dabaa, with the fourth expected to start construction in late 2023. The plant is supposed to be fully operational between 2028 and 2031[432] and cost US$30 billion[433]. See section on Egypt in Potential Newcomer Countries.
- **India** – Four reactors are under construction at Kudankulam. Construction started on the first of the units in June 2017 and on the most recent ones in December 2021. Completion of the first of these units is supposed to be reached in 2025.[434] See section on India in Annex 1.
- **Turkey** – Four reactors are being built at Akkuyu. Construction started on the first unit in 2018 and on Unit 4 in 2022. Unit 1 is now supposed to start in 2024, but commercial

428 - *WNN*, "New material promises 120-year reactor lives", *World Nuclear News*, 21 July 2015, see https://www.world-nuclear-news.org/nn-new-material-promises-120-year-reactor-lives-2107151.html, accessed 4 September 2023.

429 - Rosatom, "Projects", Undated, see https://www.rosatom.ru/en/investors/projects/, accessed 8 September 2023.

430 - Rejaul Karim Byron, "Rooppur Nuke Power Plant: Launching not before 2025", *The Daily Star*, 22 March 2023, see https://www.thedailystar.net/news/bangladesh/news/rooppur-nuke-power-plant-launching-not-2025-3277196, accessed 16 July 2023.

431 - Rosatom, "Construction begins of new units at China's Tianwan and Xudabao NPPs", Rosatom Newsletter #6, June 2021, see https://rosatomnewsletter.com/wp-content/uploads/2021/06/newsletter_06_242_main.pdf; and WNISR, "Russian Nuclear Industry Starts Nuclear Reactor Construction in China—Anyways", 26 February 2022, see https://www.worldnuclearreport.org/Russian-Nuclear-Industry-Starts-Nuclear-Reactor-Construction-in-China-Anyways.html; also WNISR, "Second Russian Nuclear Reactor Construction Start in China This Year—Anyways 2", 20 May 2022, see https://www.worldnuclearreport.org/Second-Russian-Nuclear-Reactor-Construction-Start-in-China-This-Year-Anyways-2.html; all accessed 27 August 2023.

432 - *Daily News Egypt*, "Dabaa nuclear plant project progresses according to schedule: Minister of Electricity", 14 June 2023, see https://www.dailynewsegypt.com/2023/06/14/dabaa-nuclear-plant-project-progresses-according-to-schedule-minister-of-electricity/, accessed 22 August 2023.

433 - *Power Technology*, "El Dabaa Nuclear Power Plant", 14 July 2023, see https://www.power-technology.com/projects/el-dabaa-nuclear-power-plant/, accessed 16 July 2023.

434 - Rajya Sabha, "Unstarred Question No. 3842: Status of new nuclear power plants", Department of Atomic Energy, answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 6 April 2023, see https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2023/04/2023041254.pdf, accessed 28 June 2023.

operation appears to be delayed to 2025.[435] See section on Turkey in Potential Newcomer Countries.

- **Iran** – Construction of Bushehr-2 (also called Busheer-2) originally started in February 1976 by the German company KWU-Siemens and was suspended in 1978. Work resumed in 1996, with Rosatom subsidiary ASE as the nuclear island provider. In 2022, completion has been delayed to 2026. See section on Iran in Annex 1.
- **Slovakia** – Mochovce-4, a Russian VVER design that started construction in 1985, is being completed by an international consortium and scheduled to finally be commissioned in 2024.[436] See section on Slovakia in Annex 1.

In addition, negotiations continue with Hungary around the construction of Paks II, which has been delayed and is now not expected to be completed until 2032.[437] The European Commission gave its approval for the contract changes for Paks II in May 2023, despite the ongoing conflict between Europe and Russia on energy and on the war in Ukraine.[438] As of July 2023, Rosatom's subsidiary JSC ASE was carrying out preparatory work onsite.[439] The Rosatom list also includes a nuclear reactor to be built in Finland but, due to the invasion of Ukraine, the consortium in Finland cancelled the project.[440]

It remains clear that Rosatom is the primary constructor and exporter of reactors with, as of mid-2023, building 24 out of the 58 constructed around the world (see Figure 12 and Table 2).

The relative success of Russia's export drive in a niche market of state-funded projects is not primarily the technology but the access to cheap financing accompanying the deals. According to Rosatom, it sold US$10 billion of products in 2022, an increase of 15 percent on the previous year and has an overseas order book of US$200 billion over 10 years.[441] While the value of its order book is likely to be overinflated, Rosatom is clearly pushing to remain the most influential exporter of nuclear technologies and fuel chain facilities, a 'full-service' package—as one commentator described it: "Russian nuclear power is on a roll."[442]

435 - Akkuyu Nuclear, "First Batch of Fuel Delivered to Akkuyu NPP", Rosatom, 27 April 2023, see http://www.akkuyu.com/first-batch-of-fuel-was-delivered-to-akkuyu-npp/update, accessed 29 April 2023; and Grace Symes, "Akkuyu-1 Commissioning Pushed to 2025", *Energy Intelligence, 9 June 2023, see* https://www.energyintel.com/00000188-9c8c-dfa7-aded-9fcee6050000, accessed 26 June 2023.

436 - *NEI Magazine*, "Mochovce 3 approved for energy start-up", *Nuclear Engineering International*, 20 January 2023, see https://www.neimagazine.com/news/newsmochovce-3-approved-for-energy-start-up-10531895, accessed 30 August 2023.

437 - *WNN*, "Hungary expects Paks II by 2032, plans fresh Paks operating extension", *World Nuclear News*, 9 January 2023, see https://world-nuclear-news.org/Articles/Hungary-expects-Paks-II-by-2032-plans-fresh-Paks-o, accessed 16 July 2023.

438 - *WNN*, "EC outlines approval grounds for Paks II contract amendments : Nuclear Policies", *World Nuclear News*, 30 May 2023, see https://world-nuclear-news.org/Articles/EC-outlines-approval-grounds-for-Paks-II-contract, accessed 4 September 2023.

439 - Rosatom, "ROSATOM started the first phase of construction of Paks II NPP units", Press Release, 5 July 2023, see https://www.rosatom.ru/en/press-centre/news/rosatom-started-the-first-phase-of-construction-of-paks-ii-npp-units/, accessed 28 August 2023.

440 - Fennovoima, "Fennovoima has terminated the contract for the delivery of the Hanhikivi 1 nuclear power plant with Rosatom", Press Release, 2 May 2022.

441 - Lidia Kelly, "Russia's Rosatom sees 2022 exports growth at 15% - report", *Reuters*, 26 December 2022, see https://www.reuters.com/business/energy/russias-rosatom-sees-2022-exports-growth-15-report-2022-12-26/, accessed 27 August 2023.

442 - Thane Gustafson, "Russian Nuclear Power--Unsanctioned--is Prospering Worldwide", *The Devil's Dance* on Substack, 6 January 2023, see https://thanegustafson.substack.com/p/russian-nuclear-power-unsanctioned, accessed 16 July 2023.

Nuclear Interdependencies and Sanctions

In April 2023, the U.S. Government expanded its 'Russia sanctions' to Rosatom subsidiary Rusatom Overseas, which is—or at least was—in charge of implementing the construction projects of nuclear power plants in other countries (see section above).

While the E.U. has introduced eleven different rounds of sanctions against Russia, despite many of these addressing the energy industry, these have not included measures against the nuclear sector, despite the ongoing trade in electricity, nuclear fuel, and fuel chain services.

In February 2023, the European Parliament passed a resolution that called for the expansion of the sanctions again to include individuals and entities present on the E.U. market, including Rosatom.[443] However, despite initially suggesting it would propose sanctions against the Russian commercial nuclear sector, the European Commission was reported to have abandoned such plans in February, and none have subsequently been applied.[444] There is one exception, that is the sanctions decided in February 2023 against Atomflot, a Russian company that maintains Russia's nuclear icebreaker fleet, also sanctioned by other countries including the U.S., U.K., and Canada.[445] The reason given by the European Council read:

> The icebreaker fleet managed by Atomflot is designed specifically to meet Russia's maritime transportation objectives along the Northern Sea Route—the Arctic shortcut between Europe and Asia. The Northern Sea Route has emerged as a new strategic opportunity for unlocking and monetising Russia's vast oil and gas reserves in the Arctic, thereby providing a substantial source of revenue to the government of the Russian Federation.

There are many economic and political reasons for the European inaction otherwise. According to the World Nuclear Association, Russia supplies about a fifth of all uranium conversion services and 46 percent of enrichment globally, as well as 5 percent of the world's uranium production, but Kazakhstan provides 43 percent and Uzbekistan 6.6 percent (both of which are significantly influenced by Russia).[446] According to an analysis published by the U.K. think tank Royal United Services Institute for Defence and Security Studies, based on customs data, in the year since the start of the war, Russia exported nuclear technologies and fuels worth over US$1 billion. This includes a significant increase to China, with other increases in trade with Hungary, India, and Turkey.[447]

443 - European Parliament, "European Parliament resolution of 2 February 2023 on the preparation of the EU-Ukraine Summit (2023/2509(RSP))", 2 February 2023, see https://www.europarl.europa.eu/doceo/document/TA-9-2023-0029_EN.html, accessed 8 February 2023.

444 - Leonie Kijewski and Jacopo Barigazzi, "EU Commission scratches Russia nuclear sanctions plans", *Politico*, 16 February 2023, see https://www.politico.eu/article/rosatom-russia-ukraine-volodymyr-zelenskyy-vladimir-putin-eu-executive-scratches-russia-nuclear-sanctions-plans/, accessed 16 July 2023.

445 - Council of the European Union, "Council Decision (CFSP) 2023/432 of 25 February 2023 amending Decision 2014/145/CFSP concerning restrictive measures in respect of actions undermining or threatening the territorial integrity, sovereignty and independence of Ukraine", *Official Journal of the European Union*, L 59 I/437, 25 February 2023, see https://eur-lex.europa.eu/eli/dec/2023/432/oj/eng, accessed 16 August 2023.

446 - WNA, "World Uranium Mining", World Nuclear Association, Updated August 2023, see https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx, accessed 4 September 2023.

447 - Darya Dolzikova, "Atoms for Sale: Developments in Russian Nuclear Energy Exports", Royal United Services Institute for Defence and Security Studies, 14 February 2023, see https://rusi.org/explore-our-research/publications/special-resources/atoms-sale-developments-russian-nuclear-energy-exports, accessed 1 March 2023.

Rosatom provided 31 percent of uranium enrichment services to E.U. nuclear utilities in 2021[448] and represented the largest foreign provider at 24 percent to U.S. nuclear operators in 2022.[449] According to the Euratom Supply Agency, the nameplate capacity of uranium conversion and enrichment plants in the E.U. would be "sufficient for the EU to be self-dependent", but the "Global West" would be missing enrichment capacity of 3,500–8,000 tSWU (thousand Separative Work Units) without Russia. The Agency warns that the construction of "additional conversion and enrichment capacity will take several years."[450] E.U. and U.S. nuclear utilities alone have an annual enrichment service-need of about 24,000 tSWU.[451]

Furthermore, as there are five E.U.-countries—Bulgaria, Czech Republic, Finland, Hungary, and Slovakia—operating in total 19 Soviet-designed VVER reactors, the diversification of fuel supply is more complex. Westinghouse has become a fuel supplier in Ukraine and Framatome is in the ranks to start fabricating VVER fuel. However, Westinghouse's experience had been limited to manufacturing VVER-1000 fuel, while 15 of the units in the E.U. are VVER-440 that still use different fuel and no non-Russian company has yet delivered any assemblies of that design (see Table 11). All of the countries dependent on VVER fuel have also a relatively high share of nuclear power in their respective power mix, between one third and almost 60 percent.

Westinghouse is confident to supply a first batch of VVER-440 fuel to Ukraine by the end of 2023.[452] Details on agreements about the transfer of design property-rights are unknown, thus the level of ongoing dependence on Rosatom is unclear.

Table 11 · Operating Soviet-designed Reactors in Europe (as of mid-2023)

Country	Nuclear Share 2022	VVER-1200	VVER-1000	VVER-440	Total
Armenia	31%			Armenian: 1	1
Belarus	11.9%	Belarusian: 2			2
Bulgaria	32.6%		Kozloduy: 2	-	2
Czech Republic	36.7%		Temelin: 2	Dukovany: 4	6
Finland	35.0%		-	Loviisa: 2	2
Hungary	47.0%		-	Paks: 4	4
Slovakia	59.2%		-	Bohunice: 2 Mochovce: 3	5
Ukraine	55% (2021)		Khmelnitski: 2 Rovno: 2 South Ukraine: 3 Zaporizhzhia: 6	Rovno: 2	15
All Countries					37

Sources: WNISR, with IAEA-PRIS, 2023

448 - ESA, "Euratom Supply Agency Annual Report 2021", Corrected Edition, Euratom Supply Agency, 10 August 2022, see https://euratom-supply.ec.europa.eu/system/files/2022-12/Euratom%20Supply%20Agency%20-%20Annual%20report%202021%20-%20Corrected%20edition.pdf, accessed 28 August 2023.

449 - U.S. EIA, "2022 Uranium Marketing Annual Report", Energy Information Administration, United States Department of Energy, June 2023, see https://www.eia.gov/uranium/marketing/pdf/2022%20UMAR.pdf, accessed 28 August 2023.

450 - Euratom Supply Agency, Slides from PPT Presentation at Hearing in German Federal Parliament, 6 February 2023.

451 - ESA, "Euratom Supply Agency Annual Report 2021", 2022, op.cit.; and U.S. EIA, "2022 Uranium Marketing Annual Report", 2023, op.cit.

452 - Ukrainian Energy, "Ukraine Expects to Receive Westinghouse Nuclear Fuel for VVER-440 by the end of the year", 9 March 2023, see https://ua-energy.org/en/posts/09-03-2023-7490e2b8-b75d-41d5-9676-d44c3dbc5087, accessed 21 July 2023.

How Dependent Remain Non-Russian VVER-Fuel Manufacturers on Rosatom's Cooperation/Good Will?—General Legal and Technical Observations

Background–Ever since Russia's invasion of Ukraine in 2014, efforts have accelerated to extend and develop alternatives to nuclear fuel assembly supplies for Russian designed reactors in the Ukraine (15) and in the European Union (19). Westinghouse was the first to offer VVER-1000 fuel for Ukraine and the Czech Republic. This did not go without technical glitches, and the Czech operator had switched back to Russian fuel while it remains unclear whether price or performance drove the decision. A series of new agreements and contracts has been signed between Westinghouse and Framatome—a newcomer to the VVER-fuel market that has yet to produce its first assembly—and VVER operators in the European Union and Ukraine. Does this mean future independence of the original Russian designer?

Enterprises, particularly technology companies, must continually seek competitive advantage to secure their existence and profitability. This advantage primarily resides in the collective knowledge of their employees, who understand the company's products and manufacturing processes. Additionally, national laws and privileges may play a role, such as exclusive access to essential raw materials. A company's knowledge is embodied in its employees, especially engineers and technicians who have both product and manufacturing expertise. Complex products, like nuclear reactor fuel assemblies, require years of development and repeated attempts to accumulate the necessary knowledge. As has been seen in Westinghouse's attempts to build fuel elements for Russian VVER-1000 reactors, it takes many years and many failed attempts until the necessary knowledge has been obtained.

To safeguard their knowledge, companies keep it secret, invest in research and development, and protect inventions with patents. Patents provide exclusive rights for 20 years, allowing the patent holder to take legal action against potential infringers.

This applies more when a company expands its business through a joint venture with a partner to prevent "leakage" of the company's knowledge to the partner beyond the joint venture. This is likely to be the case for the reported establishment of a joint venture between TVEL and Framatome in France with the purpose of manufacturing VVER-fuel in Germany. It should be noted that Framatome could have adopted Westinghouse's technology, but given Westinghouse's problems to develop this technology, Framatome decided to cooperate with TVEL, despite Russia's war in Ukraine and potential sanctions against Russian companies.

Framatome's hopes for complete knowledge transfer and independence are unlikely to be fulfilled, as TVEL has a strong interest in maintaining control over its expertise. This dependency is further reinforced by legal instruments such as patents and contracts.

In conclusion, the competitive advantage and knowledge protection are vital for the survival and success of enterprises, particularly in technology-related fields, such as nuclear fuel management. Joint ventures may offer collaboration opportunities but should be approached with a clear understanding of knowledge protection and the interests of the involved parties.

Russia has also developed into a major hub for nuclear education. In a recent official statement, Russia's Ministry of Foreign Affairs claimed: "We actively participate in the training and retraining of personnel for the nuclear power industry. Over 2,000 students from 65 countries study at Russian universities specializing in nuclear and related disciplines."[453]

As Russia has turned into the dominant supplier of reactor technology in the world—in fact, all 11 construction starts in the world outside China since the construction of Hinkley Point C officially began in the U.K. in 2019 and up to mid-2023, were carried out by the Russian industry (see Overview of Current New-Build)—component suppliers also largely depend on Russian projects. Examples of this co-dependency include the nuclear turbine manufacturer GEAST in France. GEAST produces the Arabelle turbines, is thus highly dependent on the niche virtually entirely controlled by the Russian nuclear industry over the past three and a half years. Reportedly, Rosatom represents about half of the GEAST turnover.[454] It was therefore no surprise that, just prior to Russia's invasion of Ukraine, the French government had offered to sell Rosatom a 20-percent share in the company.[455] The project is currently on hold.

EDF subsidiary Framatome originally planned to set up a joint-venture company with Rosatom subsidiary TVEL for the manufacturing and marketing of VVER fuel elements in its Lingen plant which is located in Germany. But when it became clear in spring of 2023 that the German government would likely oppose the deal, the Franco-Russian company was set up in France with a 25-percent participation of TVEL.[456] Whether the Lingen plant—that continues to import Russian uranium—will be able to start the manufacturing of VVER fuel elements remains open. Framatome subsidiary Advanced Nuclear Fuels (ANF) that operates the Lingen plant has submitted a licensing application for the extension of the manufacturing plant with a dedicated VVER-fuel production line. While the Lower Saxony government, which acts as the local licensing authority is opposed to the project,[457] it can only examine the application based on the Atomic Law but does not have a veto right. It is up to the federal government to greenlight or block the initiative. That decision had not been taken as of mid-2023.

The German electronics giant Siemens in cooperation with Framatome has contracted Instrumentation and Control (I&C) equipment to Rosatom for the four Akkuyu reactors in Turkey (under construction) and for the Paks II project in Hungary (in planning) as well as a range of other Russian reactor projects around the world, including in Russia itself.[458] In the

453 - Russian Ministry of Foreign Affairs, "Statement by the Head of the Delegation of the Russian Federation at the First Session of the Preparatory Committee for the 11th Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons (General debate)", Government of Russia, 1 August 2023, see https://mid.ru/en/foreign_policy/news/1899782/, accessed 11 August 2023.

454 - Eva Chibane, "General Electric : Belfort épargné face à l'abandon d'un projet finlandais de turbine Arabelle", *Le Trois*, 5 May 2022 (in French), see https://letrois.info/actualites/general-electric-belfort-epargne-face-a-labandon-dun-projet-finlandais-de-turbine-arabelle/, accessed 19 May 2022.

455 - Guillaume Guichard, "Nucléaire: l'État prêt à céder 20% d'Arabelle au russe Rosatom", *Le Figaro*, 8 March 2022.

456 - Julia Borutta, "Debatte um russisches Uran: 'Frankreich fördert indirekt Russlands Strategie'", *tagesschau.de*, 26 April 2023 (in German), see https://www.tagesschau.de/ausland/europa/frankreich-atomkraft-uran-russland-100.html, accessed 12 August 2023.

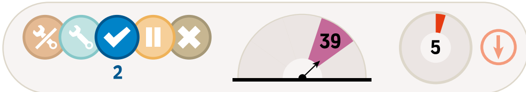
457 - Andrea Rehmsmeier, "Im Kern russisch - So abhängig ist Europas Nuklearindustrie von Russland", Radio show (in German), *Deutschlandfunk*, 17 March 2023, see https://www.deutschlandfunk.de/im-kern-russisch-europas-nuklearindustrie-und-die-abhaengigkeit-von-russland-dlf-1855dd23-100.html, accessed 12 August 2023.

458 - *NEI Magazine*, "Hungary expects France and Germany to supply I&C equipment for Paks II", 14 October 2022, see https://www.neimagazine.com/news/newshungary-expects-france-and-germany-to-supply-ic-equipment-for-paks-ii-10086599; and Greenpeace, "Russia's Atomic Partners: Framatome, Siemens Energy and Rosatom", 17 July 2023, see https://www.greenpeace.de/publikationen/Rosatom_Report_G.pdf, both accessed 2 September 2023.

case of the Turkish project, apparently, the German authorities have not yet issued any export license for the items in question.

Interdependencies between western and Russian nuclear industry interests cover all the fuel chain elements and reactor-related activities, from uranium mining to the backend services. In 2009, Rosatom acquired 100 percent of German company NUKEM Technologies focusing on Engineering and Consulting especially in Decommissioning and Waste Management services.[459]

SOUTH AFRICA FOCUS



South Africa, the only country in Africa currently operating a nuclear plant, is at a crossroads in its energy trajectory. In the past year, the country has been experiencing persistent power cuts and record electricity shortfalls that at times exceeded 6 GW.[460] South Africa is also one of the leading global carbon emitters.[461]

The economically devastating power cuts have turned electricity security into probably the leading item of public discourse and is set to dominate political debates in the lead-up to the national elections in mid-2024. Discussions around the future of the existing almost 40-year-old Koeberg nuclear power plant and the possible construction of further nuclear facilities have therefore also become more widespread.

During the year covered in this report, Koeberg has been partly shut down for major maintenance and upgrading work aimed to secure a 20-year lifetime extension beyond its originally projected 2024 closure date (see Figure 45). The shutdown has exacerbated the national electricity crisis, especially as the work is taking considerably longer than projected. The costs to the financially severely constrained national electricity utility Eskom are also proving much higher than originally announced.

In 2010, a 9.6 GW mega nuclear newbuild program had been touted as a solution to South Africa's looming electricity shortfall, but this initiative failed, partly due to financial considerations and industrial issues, but also because of the extremely controversial manner in which the project was driven. The process to take the program forward was eventually declared illegal and the entire initiative was effectively terminated. The present power crisis has however led to a revival of intense lobbying for new nuclear power plants, including the promotion of small modular reactors (SMRs). In parallel to the pro-nuclear lobbying, there has also been persistent campaigning against renewable energy, and these activities have succeeded in securing support for nuclear solutions among influential individuals, including many politicians.

459 - NUKEM, "NUKEM Technologies | Your partner for nuclear engineering", NUKEM Technologies, Undated, see https://www.nukemtechnologies.de/en/, accessed 12 August 2023.

460 - *BusinessTech*, "Stage 6 load shedding extended as units at four stations go down", 21 April 2023, see https://businesstech.co.za/news/energy/682105/stage-6-load-shedding-extended-as-units-at-four-stations-go-down/, accessed 20 August 2023.

461 - According to the World Resources Institute, South Africa is ranked 15th of the largest greenhouse gas emitting countries, see WRI, "This Interactive Chart Shows Changes in the World's Top 10 Emitters", World Resources Institute, 12 March 2023, see https://www.wri.org/insights/interactive-chart-shows-changes-worlds-top-10-emitters, accessed 31 August 2023.

Historical Background

The history of nuclear power in South Africa started with the establishment of the South African Atomic Energy Board in 1944. The coming to power of the National Party in 1948 and the subsequent institutionalization of the policy of Apartheid led to increasing international isolation and ostracization of South Africa. Partly in reaction to this, the forty years thereafter saw growing prioritization of the development of the South African nuclear sector, both civil and military. The Apartheid government saw this as both a deterrent to potential military action against the South African state as well as an energy backup option in an environment of growing international sanctions. The building of Koeberg, the first nuclear plant in Africa, started in the late 1970's, was an outcome of this strategy.[462]

When the great transition to democracy happened, culminating in the 1994 national elections, and in a global environment favoring nuclear de-escalation, South Africa had already voluntarily relinquished its nuclear military capacity. South Africa remained however a nuclear power producer, and this led to a continued push for the expansion of the nuclear capacity in the early years of the 21st century, culminating in an official plan being adopted in 2010–2011 for a massive nuclear newbuild of 9.6 GW.[463] The attempted implementation thereof, especially in an environment where the public became increasingly agitated by perceived corruption and cronyism in government, galvanized into ultimately successful opposition to this nuclear newbuild proposal. Since then, South Africa has however slipped into a worsening electricity crisis, and lobbying for new nuclear plants is again increasing.

Nuclear Capacity in South Africa

South Africa operates one nuclear plant at Koeberg with a capacity of 1854 MW. It also hosts a large facility in Pelindaba with an associated small reactor that is used for research, development, nuclear waste disposal studies, and isotope production. During the Apartheid era up to 1994, the country had a nuclear weapon program that was however terminated in 1989. South Africa has also for many decades now been associated with the mining and export of uranium.

The Koeberg Nuclear Plant

The Koeberg nuclear plant consists of two Pressurized Water Reactors (PWRs) with a nominal net capacity of 924 MW and 930 MW respectively. They were constructed according to the French Framatome CP1 design. The plant construction was started in 1976, with the two units being connected to the grid on 4 April 1984 and 25 July 1985.[464] The building work was carried out by Framatome in the face of by then considerable international opposition to

462 - David Fig, "Political Fission: South Africa's Nuclear Programme" in "Special Issue: Energy Policy and Nuclear Power – 20 Years After the Chernobyl Disaster", *Energy & Environment*, Vol. 17, No. 3, 2006, see https://www.jstor.org/stable/44397068, accessed 21 August 2023.

463 - South African Government, "Integrated Resource Plan for Electricity— Revision 2—Draft", Version 8, 8 October 2010, see https://www.energy.gov.za/irp/irp%20files/INTEGRATED_RESOURCE_PLAN_ELECTRICITY_2010_v8.pdf; and South African Government, "Integrated Resource Plan for Electricity 2010-2030— Revision 2—Final Report", 25 March 2011, see https://www.energy.gov.za/irp/irp%20files/irp2010_2030_final_report_20110325.pdf; both accessed 30 August 2023.

464 - ESKOM, "Koeberg nuclear power station", Undated, see https://www.eskom.co.za/eskom-divisions/gx/nuclear/, accessed 20 July 2023.

any form of cooperation with the white minority government and its Apartheid policies. The commissioning of the plant was delayed by a year due to the damage caused by limpet mine explosions on 18–19 December 1982. The mines had been planted during the construction by an underground operative of the then outlawed African National Congress (ANC).[465]

At its commissioning it received a 40-year operational license that is set to expire in 2024. While mostly operating without major incidents, there were some events that led to outages and investigations. The most publicized of these was perhaps the 'bolt incident' in 2005–2006.[466] Overall, in the course of its 39-year operational lifespan both units had, up to the end of 2022, achieved modest cumulative load factors of 72 percent (see Koeberg's Troubled Operational History).[467]

The Apartheid Era Nuclear Weapon Program

As an international pariah state in the 1960's to 1980's, South Africa has long had the ambition to develop a nuclear weapon arsenal that it envisaged would act as a deterrent to foreign pressure. While the development of nuclear energy plants was common around the world at that time, especially in countries that enjoyed levels of technological know-how similar to South Africa, the construction of a nuclear plant was particularly welcomed in the country, as it enabled justifying the growth of nuclear skills and capacity as being for peaceful purposes. Furthermore, while rich in coal reserves that guaranteed a level of energy security, South Africa has no oil reserves and only limited gas, so additional electricity options in the form of nuclear power assisted in mitigating the growing threat of economic sanctions.

The large-scale investment in the growth of nuclear skills resulted in a large cohort of engineers and scientists being recruited to the nuclear sector. While activities included genuine scientific research, applied technologies for medical diagnosis and treatment, and the production of isotopes, substantial effort focused not only on the development of what would become the Koeberg nuclear plant, but also on the eventual production of nuclear arms.

While it has never been clarified exactly to what extent this latter aim was achieved, on 22 September 1979 the U.S. VELA satellite detected a flash that appeared consistent with a nuclear explosion over the far Southern Ocean. It was suspected to be a nuclear test carried out either by South Africa, or by Israel with full South African cooperation.[468]

In 1989, on the eve of the South African transition to democracy, South Africa terminated its nuclear weapon program. In 1991 the country signed the Nuclear Non-Proliferation Treaty (NPT). Two years after that, just before South Africa's first democratic elections, then

465 - Jo-Ansie van Wyk, "Nuclear terrorism in Africa: The ANC's Operation Mac and the attack on the Koeberg Nuclear Power Station in South Africa", *Historia*, Vol. 60, No. 2, November 2015, see https://www.scielo.org.za/pdf/hist/v60n2/03.pdf, accessed 30 August 2023.

466 - Minister of Public Enterprises, "A Erwin: Damaged Koeberg unit", Statement to Parliament, South African Government, 17 August 2006, see https://www.gov.za/erwin-damaged-koeberg-unit, accessed 20 August 2023. The 'bolt incident' refers to a several-month-long outage of Koeberg-1 linked to a loose impediment found in the generator that the responsible Minister at the time controversially claimed might have been due to sabotage.

467 - IAEA-PRIS, "Country Statistics—Koeberg-1", Updated August 2023, International Atomic Energy Agency, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=836; and IAEA-PRIS, "Country Statistics—Koeberg-2", Updated August 2023, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=837; both accessed 31 August 2023.

468 - National Security Archive, "The Vela Flash: Forty Years Ago", Briefing Book 686, 22 September 2019, see https://nsarchive.gwu.edu/briefing-book/nuclear-vault/2019-09-22/vela-flash-forty-years-ago, accessed 6 August 2023.

president, F.W. de Klerk, conceded that the country had constructed six nuclear warheads, and that these had been dismantled in line with its obligations towards the NPT.[469]

Pelindaba Facility

The Pelindaba facility, approximately 30 km west of South Africa's capital city, Pretoria (now Tshwane), dates back to 1961, when the National Nuclear Research Institute was set up at the location. It became the site of the 20 MW SAFARI-1 reactor, designated as a research reactor.[470] The reactor has been progressively converted from high to low enriched uranium.[471] Previously operated uranium conversion, enrichment, and fuel-fabrication plants that have supplied the nuclear weapons program, the SAFARI-1 reactor, and the Koeberg plant (until 1995) have been decommissioned.[472]

In 1999, the Pelindaba facility and associated entities became a state-owned public company named the South African Nuclear Energy Corporation (Necsa). Necsa's subsidiaries NTP and Pelchem manufacture radioisotopes and fluorochemicals respectively. Necsa also used to manage the Vaalputs radioactive waste disposal site, later transferred to the National Radioactive Waste Disposal Institute which was created in 2009.

In November 2007, Pelindaba experienced a mysterious break-in by two teams of armed intruders that has been suspected of being a sophisticated attempt with insider cooperation to steal high-enriched uranium for use in nuclear explosive devices. One guard and a firefighter (not site staff, present unexpectedly) were seriously injured. The government has downplayed the event, and the intruders were never arrested.[473] More recently, the facility has experienced various breakdowns, safety scares and intense contestation for the leadership of the organization.[474]

The Vaalputs Radioactive Waste Disposal Site

Low-level radioactive waste from Koeberg and Pelindaba is transported to the waste storage site at Vaalputs, an isolated locality in the semi-desert approximately 400 km north of Cape Town and Koeberg. This site was opened in 1986.[475] Its license to operate was suspended

469 - F.W. de Klerk, "Speech by the State President, Mr. F. W. de Klerk, to a Joint Session of Parliament, 24 March 1993—Nuclear Non-Proliferation Treaty", Transcript, South African Government, 24 March 1993, submitted as Annex to "Letter Dated 12 April 1993 from the Permanent Representative of South Africa to the United Nations addressed to the Chairman of the Disarmament Commission", United Nations, 12 April 1993, published by Wilson Center, 2013, see https://digitalarchive.wilsoncenter.org/document/speech-south-african-president-fw-de-klerk-joint-session-parliment-accession-non, accessed 30 August 2023.

470 - Necsa, "Profile", The South African Nuclear Energy Corporation SOC Ltd, Undated, see https://www.necsa.co.za/about-us/, accessed 4 August 2023.

471 - Necsa, "SAFARI-1", The South African Nuclear Energy Corporation SOC Ltd, Undated, see https://www.necsa.co.za/services/safari1/, accessed 6 August 2023.

472 - WNA, "Country Profiles—Nuclear Power in South Africa", World Nuclear Association, June 2023, see https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-africa.aspx, accessed 1 September 2023.

473 - Douglas Birch and R. Jeffrey Smith, "The assault on Pelindaba", Center for Public Integrity, 14 March 2015, see http://publicintegrity.org/national-security/the-assault-on-pelindaba/, accessed 21 August 2023.

474 - Micah Reddy, "Another nuclear safety scare at Pelindaba as management fumbles", *News24*, 7 June 2018, see https://www.news24.com/news24/another-nuclear-safety-scare-at-pelindaba-as-management-fumbles-20180606; and Chris Yelland, "Fired former nuclear CEO in the running for office again", *Daily Maverick*, 7 September 2020, see https://www.dailymaverick.co.za/article/2020-09-07-fired-former-nuclear-ceo-in-the-running-for-office-again/; both accessed 21 August 2023.

475 - NRWDI, "Vaalputs National Radioactive Waste Disposal Facility—Public Information Document (PID)", National Radioactive Waste Disposal Institute, 2021, see https://nnr.co.za/wp-content/uploads/2021/02/NRWDI-PID.pdf, accessed 5 August 2023.

for a short period in 2012 due to instances of non-compliance.[476] While not involving high-level waste, which remains in local storage at Koeberg and Pelindaba, local politicians have expressed concern about the worsening state of the gravel road leading to the site which could cause an accident followed by radioactive contamination, claiming that this state of affairs is in breach of international regulations.[477]

Uranium Mining

Uranium has been identified and sometimes extracted in several of South Africa's many gold mines. In addition to these, there are several smaller designated uranium mines.[478] Forty years ago South Africa ranked amongst the world's top three producers of uranium with 14 percent of the global output, but in recent years the country's share in global production dropped to below 1 percent and even 0.1 percent in 2020.[479]

The significance of owning local uranium supply in the event of a nuclear power boom came into the spotlight a decade ago when a politically connected family controversially purchased the Shiva mine at a time when government was actively pushing for a massive nuclear newbuild.[480]

The Pebble Bed Modular Reactor Initiative

In the early 2000's, considerable efforts were invested in South Africa to develop and commercialize an SMR design originally developed in Germany in the 1980s.[481] The project became known as the Pebble Bed Modular Reactor (PBMR). In 1993, the South African national power utility Eskom obtained the license to the technology from the German HTR GmbH, who were no longer actively pursuing the technology.[482] A company was launched in 2000 and included amongst its international investors some big international players of the time like British Nuclear Fuels, and PECO, Exelon, and later Westinghouse.[483]

While claiming to have completed a successful viability study for the commercialization of the PBMR, the program encountered a range of obstacles that slowed the projected progress considerably. In 2005, the environmental advocacy group Earthlife Africa successfully

476 - Ansie Vicente and Sarah Wild, "Nuclear waste is going nowhere slowly", *The Mail & Guardian*, 2 October 2014, see https://mg.co.za/article/2014-10-02-nuclear-waste-is-going-nowhere-slowly/, accessed 21 August 2023.

477 - Rodney Kritzinger, "Vaalputs 'nuclear road' in need of urgent and sustainable repairs", Press Release, Nama-Khoi Municipality, Democratic Alliance - Northern Cape, 18 April 2023, see https://nc.da.org.za/2023/04/vaalputs-nuclear-road-in-need-of-urgent-and-sustainable-repairs, accessed 5 August 2023.

478 - Jo-Ansie Van Wyk, "The gift of gold: South Africa's uranium resources" in "Nuclear Energy in South Africa", South African Institute of International Affairs, February 2021, see https://www.jstor.org/stable/resrep32573.10, accessed 3 August 2023.

479 - OECD/NEA and IAEA, "Uranium 2022: Resources, Production and Demand", Joint Report, NEA No. 7634, 2023, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, and International Atomic Energy Agency, February 2023, see https://www.oecd-nea.org/jcms/pl_79960/uranium-2022-resources-production-and-demand?details=true, accessed 21 August 2023.

480 - Jessica Bezuidenhout, "Exclusive: Industrial Development Corporation's Gupta-deal poser", *Daily Maverick*, 13 June 2023, see https://www.dailymaverick.co.za/article/2023-06-13-exclusive-industrial-development-corporations-gupta-deal-poser/, accessed 21 August 2023.

481 - PBMR, "PBMR—Home", Pebble Bed Modular Reactor SOC Ltd, Updated 16 May 2017 see http://www.pbmr.co.za/index2.asp; and PBMR, "History", Updated 16 May 2017, see http://www.pbmr.co.za/index2.asp?Content=184; both accessed 30 August 2023.

482 - PBMR, "How did South Africa Come To The Forefront?", June 2005, see http://www.pbmr.co.za/contenthtml/files/File/HowDidSA.pdf, accessed 31 August 2023.

483 - PBMR, "History", Updated 16 May 2017, op. cit.

overturned an environmental impact assessment that had endorsed a new PBMR testing facility.[484]

More telling though, despite the involvement of many of the country's nuclear scientists and extensive government financial support, progress in operationalizing the concept was too slow. Investors withdrew from the program due to uncertain progress and ballooning costs, and the funding ultimately had to be carried by the South African Government. In the words of one analyst (in 2010):

> In 1998, they were saying that they would have the demo plant online in 2003 [at a cost of ZAR2 billion (US$$_{1998}$330 million)]. The final estimate was that the demo plant would be online in 2018 and it would cost 30 billion rands (US$$_{[2010]}$4 billion).[485]

Government funding to the program was eventually terminated in 2010. It is estimated that up to that point the PBMR had used up ZAR8.67 billion (US$$_{2010}$1.18 billion) of taxpayers' money.[486]

Considering the failure history of the PBMR development, it is surprising to see a PBMR-400 termed "preliminary design" referenced in various recent publications.[487]

Revival of Controversial Nuclear Newbuild Plans

During the nine-year term of office of former President Jacob Zuma (2009–2018), South Africa embraced a grand strategy to build new nuclear plants with a combined capacity of 9.6 GW.[488] Had this materialized, this would have been the largest public works exercise in the country's history, and it was at the time estimated to cost ZAR1 trillion (US$$_{2011}$140 billion).[489] This mega-project became very controversial in South Africa, not only because of the prohibitive costs (ZAR1 trillion then even exceeded the country's total tax revenue collected in a year), but also the construction and operating contract was in practice (though not formally) awarded to Russia's Rosatom[490]. The initiative was eventually stopped by public pressure against then President Zuma (who drove this project relentlessly) and legal intervention that pinpointed major irregularities[491] in that constitutionally required public consultation and parliamentary debate had not been carried out before the far-reaching decisions had been taken.

484 - High Court of South Africa, "Judgment: Delivered 26 January 2005—In the Matter Between Earthlife Africa (Cape Town), Applicant; and Director-General: Department of Environmental Affairs & Tourism, First Respondent; and Esom Holdings Limited, Second Respondent", Case No. 7653/03, Southern African Legal Information Institute, 2005, see http://www.saflii.org/za/cases/ZAWCHC/2005/7.html, accessed 21 August 2023.

485 - Linda Nordling, "Pebble-bed nuclear reactor gets pulled", *Nature*, 23 February 2010, see https://www.nature.com/articles/4631008b, accessed 6 August 2023.

486 - David Fig, "Nuclear Energy Rethink?—The Rise and Demise of South Africa's Pebble Bed Modular Reactor", ISS Paper 210, Institute for Security Studies, April 2010, see https://issafrica.s3.amazonaws.com/site/uploads/210.pdf, accessed 6 August 2023.

487 - For example in NRG, "Small Modular Reactors 2023—Marktanalyse", May 2023 (in Dutch), see https://www.tweedekamer.nl/downloads/document?id=2023D20547, accessed 20 October 2023.

488 - Qaanitah Hunter and Lionel Faull, "Jacob Zuma's secret nuke 'stitch-up'", *The Mail & Guardian*, 25 September 2014, see https://mg.co.za/article/2014-09-25-jzs-secrete-nuke-stich-up/, accessed 21 August 2023.

489 - Lionel Faull, "Battle for South Africa's R1-trillion nuclear contract", *The Mail & Guardian*, 7 October 2011, see https://mg.co.za/article/2011-10-07-r1trillion-nuclear-tender-bidding-war/, accessed 21 August 2023.

490 - Qaanitah Hunter and Lionel Faull, "Jacob Zuma's Secret Nuke 'Stitch-Up'", *The Mail & Guardian*, September 2014, op. cit.

491 - *fin24*, "'Justice is served', say applicants in nuclear court bid", *News24*, 26 April 2017, see https://www.news24.com/fin24/justice-is-served-say-applicants-in-nuclear-court-bid-20170426, accessed 21 August 2023.

The build was initially conceptualized as part of the national Integrated Resource Plan for Electricity published in 2011.[492] It was proposed as a suitable intervention to mitigate a large increase in electricity demand expected due to projected economic and population growth and massive electrification of previously neglected black rural areas and urban neighborhoods, as well as the planned closure of some of the oldest coal plants. It followed an unsuccessful attempt at initiating nuclear newbuild in 2008 that attracted bids from Areva and Westinghouse, which was however cancelled at the end of that year due to financial shortfalls.[493] It was also a period when renewables were still far more expensive than they are now, and before the Fukushima disaster placed major brakes on international nuclear rollouts. This ambitious nuclear newbuild program proposed in 2011 initially attracted the interest of potential bidders from France, South Korea, China, Japan, the U.S., and Russia.[494]

By 2014 it was becoming clear that Russia's Rosatom was the front runner. For example, unlike the designs then available from other bidders, the requested 9.6 GW exactly matched the capacity of eight of Rosatom's VVER 1200 MW reactors. Rosatom also established an office in Johannesburg in 2012.[495] On the political front, the Russian government was increasingly expressing their expectation to be awarded this megaproject, in the opinion of some observers as an acknowledgement by the South African government of closer ties recently established through South Africa's admission into the international BRICS (Brazil, Russia, India, China, South Africa) grouping.[496]

Russia's strategy in trying to secure this project followed the same pattern that led to Rosatom nuclear newbuilds at Rooppur in Bangladesh, El Dabaa in Egypt, and Akkuyu in Turkey (see sections on Bangladesh, Egypt and Turkey in Potential Newcomer Countries, and past WNISR editions). While details were never finalized, there were reports that Rosatom was conceptualizing a financing model for South Africa similar to the financing schemes of the abovementioned projects (variants of the Build-Own-Operate approach[497]).

South Africa's president, Jacob Zuma, was an ardent supporter of the nuclear plan and in 2014 saw it as defining his legacy. He also appeared to have struck a deal with the Russian president, Vladimir Putin, that the bid would go to Russia.[498] At the 2018–2022 Zondo Commission into State Capture, the former Minister of Finance, Nhlanhla Nene declared that pressure was exerted on him by President Zuma during a state visit to Russia in 2015 to sign a declaration that would have bound the South African government to a financial commitment and thus

492 - South African Government, "Integrated Resource Plan for Electricity 2010-2030—Revision 2—Final Report", 25 March 2011, see https://www.energy.gov.za/irp/irp%20files/irp2010_2030_final_report_20110325.pdf, accessed 3 August 2023.

493 - Anthonie Cilliers and University of the Witwatersrand, "History of nuclear in South Africa", *ESI-Africa*, 18 February 2019, see https://www.esi-africa.com/features-analysis/update-history-of-nuclear-in-south-africa/, accessed 24 September 2023.

494 - Lionel Faull, "Battle for South Africa's R1-trillion nuclear contract", *The Mail & Guardian*, 7 October 2011, see https://mg.co.za/article/2011-10-07-r1trillion-nuclear-tender-bidding-war/, accessed 30 August 2023.

495 - Rosatom, "Office profile—Sub-Saharan Africa Regional Centre", Undated, see https://rosatomafrica.com/en/regional-office/office-profile/, accessed 3 August 2023.

496 - Andrew S. Weiss and Eugene Rumer, "Nuclear Enrichment: Russia's Ill-Fated Influence Campaign in South Africa", Carnegie Endowment for International Peace, 16 December 2019, see https://carnegieendowment.org/2019/12/16/nuclear-enrichment-russia-s-ill-fated-influence-campaign-in-south-africa-pub-80597, accessed 24 September 2023.

497 - Fatih J. Thompson, "The Rise of Rosatom & Russia's Nuclear Revival", Thesis, University of Washington, 2018, see https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/42155/Thompson_washington_0250O_18604.pdf?sequence=1&isAllowed=y, accessed 24 September 2023.

498 - Qaanitah Hunter and Lionel Faull, "Jacob Zuma's Secret Nuke 'Stitch-Up'", *The Mail & Guardian*, September 2014, op. cit.

practically award the project to Russia. The Zondo Commission explicitly concluded that the refusal by the Finance Minister to do so was the leading reason why he was dismissed as Minister in December 2015.[499]

While the President's enthusiasm for the nuclear plan and his favoring of the Russian bidders may just have been influenced by political considerations, there were also numerous reports of benefactors and businesspeople close to the President who were in positions that would benefit from nuclear newbuild.[500] In particular, the Gupta family acquired the Shiva uranium mine in anticipation of greater demand for nuclear fuel with the additional future plants.[501]

The matter was thereafter taken up in court by two non-governmental organizations, Earthlife Africa and the South African Faith Communities Environment Institute [SAFCEI] who argued that the agreement with Russia was illegal. Presiding judge Lee Bozalek went further:

> Bozalek's judgment effectively declared all government's efforts to procure nuclear energy null and void. In addition to declaring South Africa's agreements with Russia, the US and South Korea unlawful and unconstitutional, he also ruled that government's 2013 and 2016 determinations to procure nuclear energy will be set aside.
>
> The judgment also determines that the request for proposals and information to start procuring nuclear energy were unlawful, unconstitutional and therefore set aside.[502]

That 2017-court ruling led to the termination of the entire initiative (see also WNISR2017 and subsequent editions). President Zuma did try to revive the Russian deal, notably by appointing one of his most trusted lieutenants, former State Security Minister David Mahlobo, to the Energy portfolio in 2017.[503] By then however considerable opposition and protests had been building up against the President with the Russian deal seen as one of the key pillars of what has been termed as "State Capture" in South Africa. At the end of 2017, at the ruling ANC's elective conference, Zuma's preferred successor suffered a narrow defeat to the current South African president, Cyril Ramaphosa.

Ramaphosa met Vladimir Putin in July 2018, and communicated to the Russian leader that South Africa no longer intended pursuing the new nuclear build.[504] This ended the saga, temporarily.

499 - Lameez Omarjee, "Zondo report: Nene's pushback on nuclear deal cost him his job", *News24*, 30 April 2022, see https://www.news24.com/fin24/economy/zondo-report-nenes-pushback-on-nuclear-deal-cost-him-his-job-20220430, accessed 21 August 2023; and Zondo Commission, "Judicial Commission of Inquiry into State Capture Report: Part IV—Vol. 1: The Attempted Capture of the National Treasury, Eoh Holdings and the City of JHB Alexkor", Judicial Commission of Inquiry into State Capture, see https://www.statecapture.org.za/site/files/announcements/680/OCR_version_-_State_Capture_Commission_Report_Part_IV_Vol_I_-_NT,EOH,COJ,Alexkor.pdf, accessed 30 August 2023.

500 - Jessica Bezuidenhout, "Zuma pals clinch first nuclear deal", *The Mail & Guardian*, 16 September 2016, see https://mg.co.za/article/2016-09-16-00-zuma-pals-clinch-first-nuclear-deal/, accessed 21 August 2023.

501 - *amaBhungane*, "Another state bonanza for the Guptas", M&G Centre for Investigative Journalism, 5 December 2014, see https://amabhungane.org/stories/another-state-bonanza-for-the-guptas/, accessed 21 August 2023.

502 - Liesl Peyper, "Energy minister to cough up for nuclear court costs", *News24*, 26 April 2017, see https://www.news24.com/fin24/energy-minister-to-cough-up-for-nuclear-court-costs-20170426, accessed 1 September 2023.

503 - Suné Payne, "Energy minister insists on nuclear", *GroundUp News*, 23 November 2017, see https://www.groundup.org.za/article/energy-minister-insists-nuclear/, accessed 21 August 2023.

504 - Sibongile Khumalo, "Ramaphosa tells Putin the time's not right for nuclear", *News24*, 27 July 2018, see https://www.news24.com/fin24/ramaphosa-tells-putin-the-times-not-right-for-nuclear-20180727-2, accessed 21 August 2023.

South Africa's Enduring Electricity Crisis

South Africa's power utility Eskom has in recent years been forced to institute rolling power blackouts due to its inability to meet national electricity demand at all times. These outages have been progressively deteriorating as breakdowns worsen at its fleet of coal power stations, which in 2022 still accounted for 85 percent of electricity production with wind and solar providing just 4.5 percent and 2.9 percent respectively.[505] At times, the outages amounted to as much as 10 hours per day,[506] and since the start of 2023, some level of power cuts have occurred almost every day[507].

The power supply crisis has turned into the country's single most important and emotional discussion point, and the cost to the economy has been estimated by the South African Reserve Bank as between ZAR204 million (US$11.7 million) a day when the power shortfall is 3 GW, and ZAR899 million (US$51.7 million) a day when the power shortfall is 6 GW.[508] The power crisis is recognized as one of the issues that is going to dominate the national discourse for some time still and is expected to shape the outcome of the 2024 national elections.[509] Recognizing the severity of the electricity crisis, the government went as far as declaring it a national State of Disaster on 9 February 2023 (terminated two months later).[510]

The Dwindling Performance of South Africa's Power Plants

The electricity crisis in South Africa is largely caused by increasingly frequent technical problems at the country's large fleet of coal power stations. The electricity availability factor (the percentage of the power that can be delivered at any particular time relative to the total capacity) has been steadily decreasing over the years. In the first half of 2023, it fell below 50 percent on some days.[511]

The Koeberg nuclear power plant generated 10.12 TWh in 2022, a drop of 17 percent over the previous year, bringing its share in the national electricity mix to 4.9 percent, down 1.1 percentage points. The last time both units were operating together was just before Koeberg-1's shutdown for lifetime extension upgrades on 10 December 2022. Since then, Koeberg-2 experienced short interruptions twice. This means that Koeberg-2 has unexpectedly lost generating capacity three times since it was reconnected to the grid in August 2022

505 - EMBER, "Africa", Ember, 28 March 2022, see https://ember-climate.org/countries-and-regions/regions/africa/, accessed 6 August 2023.

506 - Promit Mukherjee, "South Africa nearing end of daily power cuts, minister says", *Reuters*, 2 July 2023, see https://www.reuters.com/world/africa/south-africa-nearing-end-daily-power-cuts-minister-says-2023-07-02/, accessed 31 August 2023.

507 - *BusinessTech*, "204 days of load shedding – and counting", 23 June 2023, see https://businesstech.co.za/news/energy/697911/204-days-of-load-shedding-and-counting/, accessed 6 August 2023.

508 - *Bloomberg*, "Stage 6 load shedding costs South Africa R900 million a day: SARB", as published by *BusinessTech*, 6 February 2023, see https://businesstech.co.za/news/energy/662515/stage-6-load-shedding-costs-south-africa-r900-million-a-day-sarb/, accessed 6 August 2023.

509 - Ferial Haffajee, "Rolling Blackouts Backlash—Torched by power cuts, the middle class will load shed the ANC in 2024 – survey", *Daily Maverick*, 14 March 2023, see https://www.dailymaverick.co.za/article/2023-03-14-torched-by-power-cuts-the-middle-class-will-load-shed-the-anc-in-2024-survey/, accessed 6 August 2023.

510 - Department of Cooperative Governance, "Government terminates National State of Disaster on electricity supply constraints", Press Release, South African Government, 5 April 2023, see https://www.gov.za/speeches/government-terminates-national-state-disaster-%C2%A0electricity-supply-constraints-5-apr-2023, accessed 24 September 2023.

511 - *Daily Investor*, "Eskom in deep trouble", 21 May 2023, see https://dailyinvestor.com/business/17874/eskom-in-deep-trouble-2/, accessed 20 August 2023.

following its lengthy shutdown and mid-2023.[512] (See Figure 45). Meanwhile, Koeberg-1, which was initially expected to undergo a six-month refurbishment outage, is now set to resume production after eleven months, in November 2023.[513]

Koeberg's Troubled Operational History

Ever since their grid connection in the middle of the 1980s, the operational history of the two Koeberg reactors supplied by France has been roller-coaster (see Figure 44). It took Unit 1 until 1997 to achieve a full year with a load factor exceeding 80 percent. Since then, in nine of the 25 years, its load factor remained below 70 percent.

In the first 15 full years of operation from 1986–2000, Unit 2 has seen only three times a load factor beyond 80 percent. Since then, in nine of the 22 years, its load factor remained below 70 percent.

Not surprisingly, the lifetime load factors of both units remain at just over 70 percent very modest by international comparison. The average annual load factor of the world nuclear fleet has been around 80 percent over the past five years.[514] Small programs with less than five units frequently experience lifetime load factors in the high eighties.

The 18-month period between January 2022 and July 2023 has seen a range of events that have impacted the operation of the Koeberg reactors that are now respectively in their 40th and 39th year of operation since startup.

Chronology of Events January 2022–July 2023

18 January 2022 – Koeberg-2 is shut down for major works to meet requirements for lifetime extension, including the replacement of steam generators and routine refueling.

24 January 2022 – Koeberg-1 unplanned shutdown; reportedly, a technician cut a valve on the active Koeberg-1 rather than the shutdown Koeberg-2. The plant is down for almost a day, and power is slowly ramped up again over the following two days.

7 August 2022 – Koeberg-2: after nearly seven months offline, much longer than the projected outage period of five months and without having achieved the main purpose of the outage (steam generator replacement), the reactor starts being powered up again; normal power output is again reached on 14 August.

19 August 2022 – Koeberg-2 suddenly powers down because the control rods developed a "mechanical problem" (not further specified).

512 - Eskom, "Eskom Data Portal", Undated, see https://www.eskom.co.za/dataportal/, accessed 21 August 2023.

513 - Eskom, "Koeberg Unit 1 outage delayed to allow stability of the power system", Press Release, 8 December 2022, see https://www.eskom.co.za/koeberg-unit-1-outage-delayed-to-allow-stability-of-the-power-system/; and Eskom, "Eskom provides feedback on Koeberg Unit 1's planned maintenance and gives assurance that the Long-Term Operation (LTO) project is on track", Press Release, 17 August 2023, see https://www.eskom.co.za/eskom-provides-feedback-on-koeberg-unit-1s-planned-maintenance-and-gives-assurance-that-the-long-term-operation-lto-project-is-on-track/; accessed 31 August 2023.

514 - IAEA-PRIS, "World Statistics—Load Factor Trend", Updated 20 October 2023, see https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendinAverageLoadFactor.aspx, accessed 20 October 2023.

25 August 2022 – Koeberg-2 is restarted, and full power is achieved on the same day.

3 September 2022 – Koeberg-2 trips during a control-rod test. The outage lasts three weeks.

25 September 2022 – Koeberg-2 is restarted achieving full power the following day.

10 December 2022 – Koeberg-1 is shut down for lifetime-extension refurbishing (including refueling). The outage is then scheduled to last until June 2023. As of early October 2023, return to service is scheduled for November 2023.

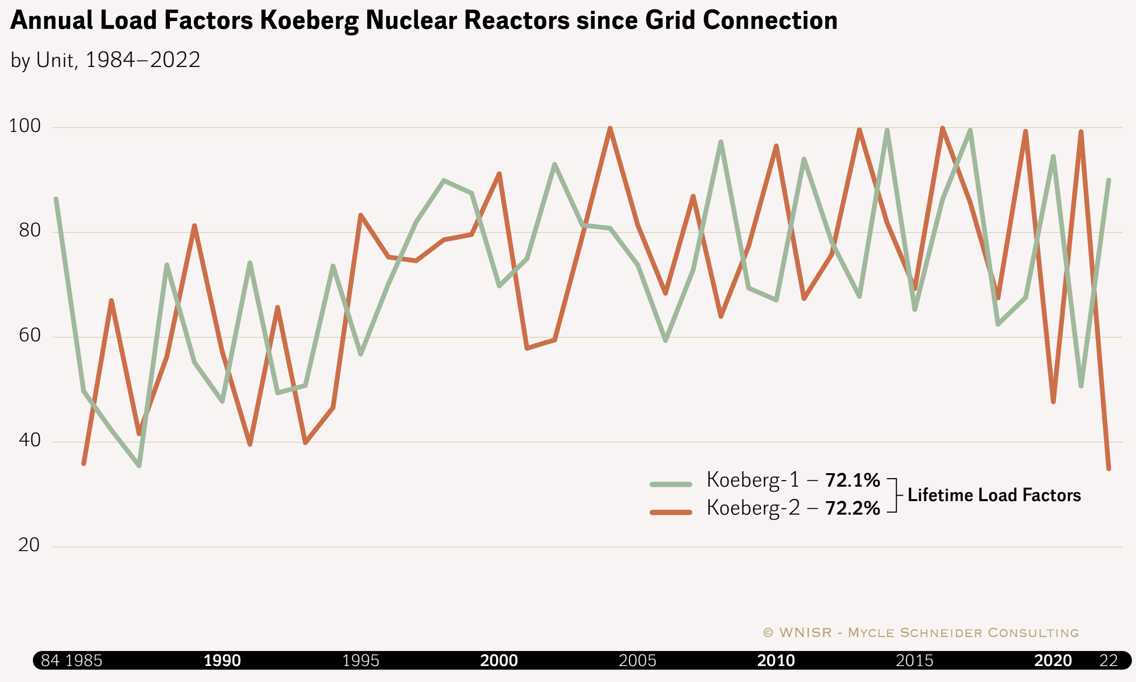
17 February 2023 – Koeberg-2 trips "while replacing a failed electronic turbine protection module". The system returns to full operation 24 hours later.

15 April 2023 – Koeberg-2 shuts down due to "problems with its feedwater pumps". 70 percent of its capacity is restored on 17 April, and full power on 19 April.

14 June 2023 – Koeberg-2 experiences a 30-percent power loss (reasons unclear); full power is restored four days later.

Sources: Various, compiled by WNISR, 2023

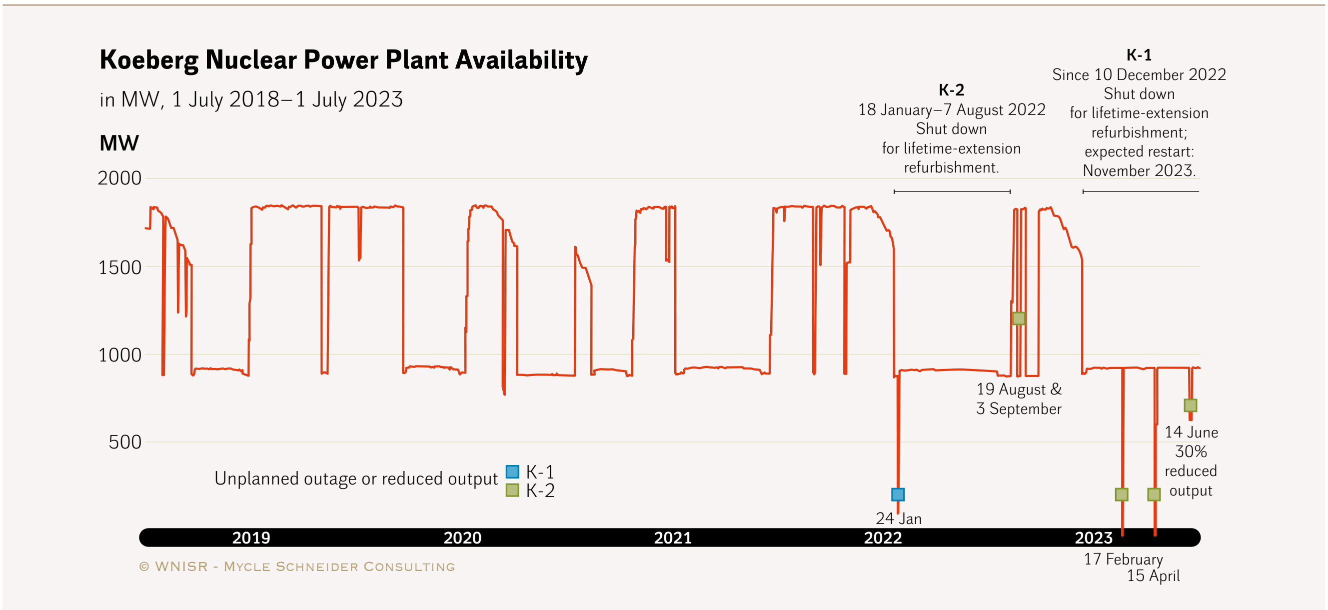
Figure 44 · Historical South African Nuclear Reactor Performance, 1984–2022



Source: IAEA-PRIS, 2023

Note: Grid connection dates: Koeberg-1 on 4 April 1984, Koeberg-2 on 25 July 1985.

Figure 45 · Recent South African Nuclear Power Plant Performance



Source: Eskom, 2023[515]

The Current South African Electricity Plan

South Africa's most recent official electricity management and development roadmap, the Integrated Resource Plan for Electricity 2019 (IRP 2019),[516] was published in the Government Gazette in October 2019. The plan estimates future electricity demand and projects an outline of new generating capacity (only specifying technologies) and plant closures for each year until 2030. It marked a significant move away from nuclear energy. In particular, the 9.6 GW build listed in the previous IRP from 2010 had been removed. Instead, the IRP2019 explicitly advocates a 20-year life extension of the two units at Koeberg to 2044.

The IRP2019 also includes an ambiguous reference to potential future 2.5 GW of nuclear:

> Decision 8: Commence preparations for a nuclear build programme to the extent of 2 500 MW at a pace and scale that the country can afford because it is a no-regret option in the long term.[517]

These 2,500 MW appear to have been a late addition to the document.[518]

The IRP2019 timeline lists no addition of nuclear generating capacity until 2030. Despite this, the now combined Ministry of Mineral Resources and Energy has been quick to get the ball rolling, seeking to lay the ground for a round of expressions of interest. In 2021, the Ministry had foretold it would issue a request for proposal in late FY2021 in order to finalize the

515 - Eskom, Response to Data Request Form, received on 20 August 2023, see https://www.eskom.co.za/dataportal/data-request-form/.

516 - Department of Mineral Resources and Energy, "Integrated Resource Plan (IRP2019)", October 2019, South African Government, see https://www.gov.za/sites/default/files/gcis_document/201912/42784gon1360.pdf, accessed 1 September 2023.

517 - Ibidem.

518 - Lameez Omarjee and Jan Cronje, "Government gazetted wrong version of master energy plan - report", *News24*, 18 October 2019, see https://www.news24.com/fin24/Economy/Eskom/government-gazetted-wrong-version-of-master-energy-plan-report-20191018, accessed 21 August 2023.

procurement in 2024.[519] This has however not materialized to date, yet in May 2023, Minister Mantashe maintained that the procurement would be completed by the 2024 deadline, while announcing that a request for proposals would be launched in Q4 of FY2023.[520] At the same time, the initiation of new bidding rounds for renewable energy projects is now two years behind schedule.

Lacking Government Action on Renewables and Divisions in the Ruling Party

Other than the disturbingly frequent breakdowns at the coal power stations, the electricity crisis has also been exacerbated by a reluctance from critical sectors in government (notably the Department of Mineral Resources & Energy—DMRE) to vigorously drive the expansion of solar and wind projects—which are exceptionally well suited to the South African weather.[521]

An episode that well illustrates the partisan position of influential politicians is the dismissal in February 2022 from the board of the National Nuclear Regulator (NNR) of Peter Becker, a leading member of the South African anti-nuclear activist group Koeberg Alert. The reason given by the responsible DMRE Minister Gwede Mantashe is that

> If you resist nuclear and you [are] a board member, I fire you, simple. You can't be [on] a board of something you're not advocating for.[522]

Peter Becker, who had been nominated by several community groups and appointed in June 2021 by Minister Mantashe himself to serve as a civil society representative on the NNR board, subsequently successfully challenged his dismissal in a court of law that rendered its judgment in early 2023.[523] In May 2023, the same judge rejected an application filed by the Minister and NNR to bring the case before the Supreme Court of Appeal.[524]

In contrast to this, President Cyril Ramaphosa has at numerous points expressed strong support for a vastly expanded renewable energy rollout, as well as promoting the Just Energy Transition initiative, which seeks to develop renewable energy plants near the sites of coal plants earmarked for closure and the retraining of coal sector workers. He is strongly endorsing

519 - Department of Mineral Resources & Energy, "NERSA Concurrence With the Section 34 Determination for 2 500MW of New Nuclear Generation Capacity", Press Release, 27 August 2021, see https://www.energy.gov.za/files/media/pr/2021/NERSA-Concurrence-with-The-Section34Determination-for-2500mw-New-Nuclear-Generation-Capacity.pdf, accessed 31 August 2023.

520 - Terence Creamer, "Mantashe outlines procurement schedules, including for nuclear, as he confirms IRP delay", *Engineering News*, 16 May 2023, see https://www.engineeringnews.co.za/article/mantashe-outlines-procurement-schedules-including-for-nuclear-by-2024-as-he-confirms-irp-delay-2023-05-16, accessed 21 August 2023.

521 - SANEDI, "Global Solar Atlas—Map and Data Downloads—South Africa", South African National Energy Development Institute, Undated, see https://globalsolaratlas.info/download/south-africa; and SANEDI, "Wind Atlas for South Africa (WASA)", 2019, see https://www.wasaproject.info/; also, IRENA, "Renewable Energy Prospects: South Africa", International Renewable Energy Agency, June 2020, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_REmap_South_Africa_report_2020.pdf?rev=4c91c220ae4b441dbbfaf1ce36c2d3ec; all accessed 31 August 2023.

522 - Tania Broughton, "Gwede Mantashe axing of nuclear watchdog activist Peter Becker was unconstitutional, rules court", *Daily Maverick*, 20 January 2023, see https://www.dailymaverick.co.za/article/2023-01-20-gwede-mantashe-axing-of-nuclear-watchdog-activist-peter-becker-was-unconstitutional-rules-court/, accessed 31 August 2023.

523 - Office of the Chief Justice for the Western Cape Division, "Judgment Delivered 19 January 2023—In The Matter Between Peter Becker, Applicant; vs. Minister of Mineral Resources & Energy, First Respondent; National Nuclear Regulator, Second Respondent; Chairperson of the Board of Directors of the National Nuclear Regulator, Third Respondent", Case No. 3473/2022, see https://www.groundup.org.za/media/uploads/documents/skm_c65823011912100.pdf, accessed 31 August 2023.

524 - Lameez Omarjee, "Mantashe, regulator lose court bid against anti-nuclear activist", *News24*, 29 May 2023, see https://www.news24.com/fin24/climate_future/energy/mantashe-regulator-lose-court-bid-against-anti-nuclear-activist-20230529, accessed 31 August 2023.

the major investment in this program.[525] The Just Energy Transition Implementation Plan envisages the investment of US$8.5 billion over the five-year period 2023–2027 pledged by several developed nations for initiatives that will promote the decarbonization of the electricity sector, as well as the introduction of green hydrogen and electric vehicle developments.[526]

South African Nuclear Sector Developments

After an aborted start in 2022, the past year has seen work begin at Koeberg to implement the plant maintenance and upgrades required to secure the plant's life extension to 2044. There have been controversies surrounding the termination of a fuel supply agreement with the United States. And, in view of South Africa's worsening electricity supply shortages and increasing periods of rolling power cuts, lobbying for the construction of new nuclear plants has intensified (even if this obviously does not represent a short-term option to address the power crisis).

Koeberg's Lifetime Extension

The Koeberg refurbishment project is now effectively over a year behind schedule and looks increasingly set to drag on well past the 31 July 2024 deadline when its operating license expires. This has various regulatory implications, as well as aggravating the electricity crisis.

The lifetime extension of Koeberg beyond its initially projected 40-year operating span has been treated as a given for some time. Major operations to replace a variety of components, in particular the plant's six steam generators, have been planned for over a decade (see previous WNISR editions). As the South African electricity crisis has grown more acute, the need to keep large electricity producing facilities such as Koeberg going for as long as possible has been considered increasingly crucial. A 20-year extension of the ageing nuclear plant has accordingly been recommended in the most recent IRP. In order to approve the extension, the South African National Nuclear Regulator requires a series of maintenance operations and instrumental replacements to be carried out. The most significant of these is the replacement of the six steam generators.

The projected costs of these upgrades was quoted in 2010 to be ZAR20 billion (US$$_{2010}$ 2.7 billion).[527] There are now signs that the final costs are going to be considerably higher, though no revised figure is being put forward by Eskom.[528] It has been claimed that

525 - Presidential Climate Change Commission, "President Ramaphosa outlines South Africa's Just Energy Transition Investment Plan", Press Release, Presidency of the Republic of South Africa, 4 November 2022, see https://www.thepresidency.gov.za/press-statements/president-ramaphosa-outlines-south-africa%E2%80%99s-just-energy-transition-investment-plan, accessed 21 August 2023.

526 - Presidential Climate Commission, "South Africa's Just Energy Transition Investment Plan (JET-IP)", 2023, see https://www.climatecommission.org.za/south-africas-jet-ip, accessed 31 August 2023.

527 - Chris Yelland, "R20bn life extension of Koeberg power station poses significant risks for South Africa", *Daily Maverick*, 28 November 2021, see https://www.dailymaverick.co.za/article/2021-11-28-r20bn-life-extension-of-koeberg-power-station-poses-significant-risks-for-south-africa/, accessed 20 July 2023.

528 - Terence Creamer, "R20bn Koeberg life-extension cost estimate of 2010 now 'significantly different'", *Engineering News*, 27 September 2022, see https://www.engineeringnews.co.za/article/r20bn-koeberg-life-extension-cost-estimate-of-2010-now-significantly-different-2022-09-27, accessed 31 August 2023.

some of these additional costs are to be covered by the Koeberg maintenance budget, the justification then being that these are routine replacements part of normal plant operations.[529]

The steam generator replacements of Koeberg-2 were scheduled to coincide with the unit's refueling outage between January and June 2022.[530] While never fully explained by the utility, reports indicate that work could not proceed as planned because the utility failed to construct the storage facilities for the contaminated old steam generators in time. Indicative of the disorganized manner in which the project management has proceeded is an incident—the second time in as many months—during the Koeberg-2 shutdown, a technician mistakenly cut a valve of the running Koeberg-1 while intending to execute this same action on the equivalent valve of the inactive Koeberg-2.[531] The steam generator replacement operation was then postponed, with Koeberg-2 eventually being returned to service in mid-August 2022 with the original steam generators (i.e. 7 months after the start of an outage originally scheduled for 5 months), though two more outages occurred in the following weeks.[532]

On 10 December 2022, Koeberg-1 was taken offline to start refurbishment work, including the replacement of its steam generators.[533] The six months projected for this operation proved insufficient, and Eskom's completion time estimate then became October 2023. In July 2023, South Africa's Electricity Minister already indicated that he was "worried and extremely upset" about the delayed completion of this project, highlighting that the Koeberg-1 shutdown was now likely to extend into the period in which Koeberg-2 was to finally be fitted with its new steam generators.[534] In August 2023, Koeberg's current acting Chief Nuclear Officer indicated that the new steam generators had now been moved into position.[535] Regarding the lengthy time overruns, he stated that

> In a nutshell we were overly optimistic in terms of what we thought we could achieve and, in hindsight, if we could have done it differently we would have scheduled a [much] longer time for this intervention.[536]

529 - *BusinessTech*, "New delays at South Africa's nuclear power station add to load shedding woes", 17 May 2023, see https://businesstech.co.za/news/energy/688631/new-delays-at-south-africas-nuclear-power-station-add-to-load-shedding-woes/, accessed 24 September 2023.

530 - Eskom, "Update on Koeberg Unit 2 long term outage and steam generator replacement project", Press Release, 4 March 2022, see https://www.eskom.co.za/update-on-koeberg-unit-2-long-term-outage-and-steam-generator-replacement-project/, accessed 4 April 2022.

531 - Sasha Planting, "Latest red flag raised at Koeberg involves contractor making a 'critical error'", *Daily Maverick*, 16 March 2022, see https://www.dailymaverick.co.za/article/2022-03-16-latest-red-flag-raised-at-eskoms-koeberg-station-involves-contractor-making-a-critical-error/, accessed 20 August 2023.

532 - Hanno Labuschagne, "Koeberg unit quits again — Here is a timeline of its many troubles in 2022", *My Broadband*, 6 September 2022, see https://mybroadband.co.za/news/energy/459301-koeberg-unit-quits-again-here-is-a-timeline-of-its-many-troubles-in-2022.html, accessed 20 August 2023.

533 - Eskom, "Koeberg Unit 1 outage delayed to allow stability of the power system", Press Release, 8 December 2022, see https://www.eskom.co.za/koeberg-unit-1-outage-delayed-to-allow-stability-of-the-power-system/, accessed 31 August 2023.

534 - Terence Creamer, "Ramokgopa 'worried and extremely upset' over Koeberg outage slips", *Engineering News*, 23 July 2023, see https://www.engineeringnews.co.za/article/ramokgopa-worried-and-extremely-upset-over-koeberg-outage-slips-2023-07-23; and Victoria O'Regan, "Koeberg power station's Unit 1 back online by November", *Daily Maverick*, 11 August 2023, see https://www.dailymaverick.co.za/article/2023-08-11-koeberg-power-stations-unit-1-set-to-be-finally-back-online-by-november-featherstone/; both accessed 31 August 2023.

535 - Western Cape Government, "Premier's 20th Energy Digicon looks at the importance of Koeberg Power Station", Press Release, 14 August 2023, see https://www.westerncape.gov.za/news/premier%E2%80%99s-20th-energy-digicon-looks-importance-koeberg-power-station, accessed 16 August 2023.

536 - Victoria O'Regan, "Koeberg power station's Unit 1 back online by November", *Daily Maverick*, 11 August 2023, see https://www.dailymaverick.co.za/article/2023-08-11-koeberg-power-stations-unit-1-set-to-be-finally-back-online-by-november-featherstone/, accessed 16 August 2023.

As of August 2023, the projected completion day for the operation has now been moved further back to November 2023.[537]

A further sign that the work appears not to be going as planned is that one of Eskom's most senior officials, the Chief Operating Officer, who had been retained to manage the project, has suddenly left after less than a month in this role without reasons given for his departure.[538] Koeberg is also only under temporary general nuclear management since the departure of the previous Chief Nuclear Officer in July 2022.[539]

Fuel Supply Uncertainties

The U.S.-South Africa so-called 123 agreement that enabled Westinghouse to supply nuclear fuel to Koeberg lapsed on 4 December 2022. The reasons for why this agreement was not renewed prior to lapsing has not been fully explained. One given reason is that South Africa has hinted on its intention to fabricate its own fuel again, triggering proliferation concerns in the U.S. Others have speculated the move would be an indicator of U.S. displeasure and growing mistrust with the South African state's comparatively close relationship with Russia at a time of global polarization due to the war in Ukraine.[540]

The nuclear fuel supply arrangement is currently split between Westinghouse, which provides the fuel assemblies for Koeberg-1, and Framatome, which supplies Koeberg-2. Koeberg-1 is being refueled during the current outage, but there is now no certainty regarding future fuel supplies.[541] In March 2023, the South African Minister of Mineral Resources and Energy stated that the U.S. and South Africa were actively engaging with the aim of reinstating the fuel-supply agreement, and that permission had now been granted to Westinghouse to produce and deliver the next round of nuclear fuel.[542]

At the end of July 2023, South Africa's NECSA signed a Memorandum of Understanding to build stronger bilateral collaboration with Russia's TVEL.[543] Nuclear fuel purchase and production is highlighted in particular, and thus establishes Russia as a likely preferred replacement to the current French and U.S. suppliers. This is set to enhance perceptions that South Africa

537 - Terence Creamer, "Koeberg Unit 1 now only scheduled to re-enter operation on November 3", *Engineering News*, 10 August 2023, see https://www.engineeringnews.co.za/article/koeberg-unit-1-now-only-scheduled-to-re-enter-operation-on-november-3-2023-08-10, accessed 31 August 2023.

538 - *News24Wire*, "Jan Oberholzer to leave Eskom in shock development", *Engineering News*, 18 July 2023, see https://www.engineeringnews.co.za/article/jan-oberholzer-to-leave-eskom-in-shock-development-2023-07-18, accessed 6 August 2023.

539 - Eskom, "Leadership changes at Eskom's Koeberg Nuclear Power Station as Chief Nuclear Officer leaves to join Canadian nuclear operator", Press Release, 11 July 2022, see https://www.eskom.co.za/leadership-changes-at-eskoms-koeberg-nuclear-power-station-as-chief-nuclear-officer-leaves-to-join-canadian-nuclear-operator/, accessed 20 August 2023.

540 - Peter Fabricius, "Why the US blocked exports of nuclear fuel components to Koeberg", *Daily Maverick*, 24 May 2023, see https://www.dailymaverick.co.za/article/2023-05-24-a-new-look-into-why-the-us-blocked-exports-of-nuclear-fuel-components-to-koeberg/, accessed 16 August 2023.

541 - Terence Creamer, "DMRE promises urgency as Koeberg seeks to secure ongoing supply of Westinghouse fuel", *Engineering News*, 3 February 2023, see https://www.engineeringnews.co.za/article/dmre-promises-urgency-as-koeberg-seeks-to-secure-ongoing-supply-of-westinghouse-fuel-2023-02-03, accessed 3 August 2023.

542 - Christian Themba Msimang and Minister of Mineral Resources and Energy, "Questions asked to the Minister of Mineral Resources and Energy—2023-w683", People's Assembly, 10 March 2023, see http://www.pa.org.za/questions/questions-asked-to-the-minister-of-mineral-resou-4/2023-w683-10-march-2023, accessed 24 September 2023.

543 - NECSA and Rosatom, "TVEL and Necsa Sign MoU to collaborate on nuclear technology for peaceful means", Press Release, 1 August 2023, see https://www.necsa.co.za/wp-content/uploads/2023/08/Media-statement-TVEL-and-Necsa-Signing-MoU.pdf, accessed 31 August 2023.

is gravitating away from its traditional French and U.S. trade partners and towards closer links with the Russian state and is now exhibiting a pro-Russian bias at times of heightened geopolitical instabilities induced by the war in Ukraine.[544]

Renewed Talk of Nuclear Newbuild in South Africa

South Africa's grave power crisis has spawned numerous propositions of how to effectively expand the missing electricity capacity. This has included numerous suggestions that this can be best achieved through new nuclear plants. The lobbying for new nuclear has been driven by a variety of figures across the political spectrum. The most influential nuclear promoter has been the Minister of Mineral Resources and Energy. His position is shared by many other senior figures in the ruling ANC, although there appear to be widely diverging viewpoints on the energy policy direction within the party.

The third-largest party, the Economic Freedom Fighters, has advocated for the building of new nuclear plants, expressly stating that these should be built by Russia.[545] Other figures have warmed to suggestions to import small modular reactors, vocal proponents of which include the former leader of the largest parliamentary opposition party (Democratic Alliance)[546] and the Afrikaner lobby movement Afriforum[547].

Rosatom has been quick to come forward as a potential international partner by actively marketing its nuclear power ships as a relatively fast solution to the country's electricity crisis.[548] Russia's only operating small reactors on a barge have been disappointing however with close to 13 years construction time and very low load factors since commissioning (see section on Russia in chapter on SMRs).

Navigating South Africa Through Its Worsening Power Crisis in 2023

Despite experiencing far more severe electricity shortages in 2023 than in recent years, there have been early signs that South Africa is starting to adapt and implementing policies that could extract the country out of the crisis. The long neglected domestic solar industry has been booming as large organizations, businesses, and households have scrambled to escape the deepening power cuts by installing rooftop solar systems.[549] The building of medium-scale

544 - Crystal Orderson, "A 'Russian love affair': Why South Africa stays 'neutral' on war", *Al Jazeera*, 2 June 2023, see https://www.aljazeera.com/features/2023/6/2/a-russian-love-affair-why-south-africa-stays-neutral-on-war, accessed 6 August 2023.

545 - EFF, "EFF Media Statement Following the 18th Central Command Team Meeting and 4th Annual Plenum of the 2nd National People's Assembly", Press Release, Economic Freedom Fighters, 29 January 2023, see https://effonline.org/wp-content/uploads/2023/03/29-01-23_EFF-MEDIA-STATEMENT-FOLLOWING-THE-18th-CENTRAL-COMMAND-TEAM-MEETING-AND-4th-ANNUAL-PLENUM-OF-THE-2nd-NATIONAL-PEOPLES-ASSEMBLY.pdf, accessed 20 August 2023.

546 - Mmusi Maimane, "State inaction on energy crisis infringes rights, deepens injustice", Leader of Build One SA, published in *Daily Maverick*, 20 March 2023, see https://www.dailymaverick.co.za/opinionista/2023-03-20-state-inaction-on-energy-crisis-infringes-rights-deepens-injustice/, accessed 20 August 2023.

547 - *TechCentral*, "Inside AfriForum's plan to deploy modular nuclear reactors in SA", 3 February 2023, see https://techcentral.co.za/tcs-inside-afriforums-plan-to-deploy-modular-nuclear-reactors-in-sa/221726/, accessed 20 August 2023.

548 - *Moneyweb*, "Nuclear powerships offer clean baseload electricity at predictable prices – Rosatom", 20 April 2023, see https://www.moneyweb.co.za/news/south-africa/nuclear-powerships-offer-clean-baseload-electricity-at-predictable-prices-rosatom/, accessed 21 August 2023.

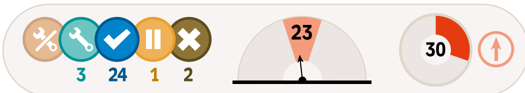
549 - *BusinessTech*, "Solar boom in South Africa as private investors sweep in with R300 million", 31 July 2023, see https://businesstech.co.za/news/energy/707872/solar-boom-in-south-africa-as-private-investors-sweep-in-with-r300-million/, accessed 21 August 2023.

solar and wind farms has also been boosted by the removal of restrictive regulations that greatly complicated the development of private facilities in the 1–100 MW capacity range.[550]

On the political front, recognizing that the dire state of electricity supply presented a threat to the ruling party re-election bid at the 2024 national elections, the president created a new ministerial post, the Minister of Electricity, appointed in March 2023 to specifically intervene and implement concrete measures to mitigate the electricity crisis.[551] While this appointment has been met with some cynicism given that few believe that there are short-term solutions to the energy crisis, it has allowed the President to assert the government is trying to do what it can to alleviate the difficult situation.

To the surprise of most analysts, South Africa has been able to get through its coldest months in 2023, when electricity demand is at its annual peak, with smaller power shortfalls than anticipated.[552] This is to some extent due to lower electricity demand on the grid than projected, and partly due to the much greater penetration of solar devices, with recent reports claiming a 349 percent increase in solar rooftop installations between March and June 2023.[553]

SOUTH KOREA FOCUS



South Korea (the Republic of Korea) is the fifth largest nuclear power producer in the world. It operates 24 reactors and has one reactor in LTO, including 22 Pressurized Water Reactors (PWRs) and three Pressurized Heavy Water Reactors (PHWRs). As of September 2023, there are three reactors—all Korean made APR-1400 type—under construction. So far, two reactors, Kori-1 and Wolsong-1, have been closed, in 2017 and 2019 respectively. In April 2023, then the oldest reactor, Kori-2, was shut down after 40 years of operation; however, as it is expected to be restarted, it is considered in LTO.

The Yoon government is upping support for the nuclear industry whose state-controlled flagship enterprise Korean Electric Power Company (KEPCO) has cumulated an unprecedented net debt of US$149 billion.

Nuclear Power Plant Name Changes

There used to be four nuclear power plant sites in South Korea, namely Kori, Wolsong, Hanbit, and Hanul. However, on 3 January 2017, the Kori plant was divided into Kori in Busan and Saeul

550 - Marianne Merten, "Increase to 100MW embedded generation threshold will give 'oomph' to South African economy, says Ramaphosa", *Daily Maverick*, 10 June 2021, see https://www.dailymaverick.co.za/article/2021-06-10-increase-to-100mw-embedded-generation-threshold-will-give-oomph-to-south-african-economy-says-ramaphosa/, accessed 21 August 2023.

551 - Presidency of the Republic of South Africa, "President sets out roles and responsibilities of the Minister of Electricity", Press Release, Government of South Africa, 26 May 2023, see https://www.thepresidency.gov.za/press-statements/president-sets-out-roles-and-responsibilities-minister-electricity, accessed 21 August 2023.

552 - *BusinessTech*, "The truth behind lower stages of load shedding in South Africa", 19 July 2023, see https://businesstech.co.za/news/energy/705073/the-truth-behind-lower-stages-of-load-shedding-in-south-africa/, accessed 21 August 2023.

553 - Shaun Jacobs, "South Africa's solar panel imports hit new record", *Daily Investor*, 3 August 2023, see https://dailyinvestor.com/energy/26209/south-africas-solar-panel-imports-hit-new-record/, accessed 24 September 2023.

in Ulsan.[554] And in November 2022, almost six years later, Korea Hydro & Nuclear Power (KHNP) officially changed the names of the reactors at the Saeul site. The operating Shin-Kori-3 & -4 became Saeul-1 & -2, and Shin-Kori-5 & -6 under construction became Saeul-3 & -4.

Until the restructuring of January 2017, Kori was destined to be the largest nuclear power plant complex in the world upon completion of Shin-Kori-4 (later Saeul-2). Yet, after the separation of Kori and Saeul, the title of the world's largest nuclear power plant has been kept by the Hanul site. At Hanul, in addition to the Hanul-1 to -6 and Shin-Hanul-1, Shin-Hanul-2 is waiting for an operating license approval from the Nuclear Safety and Security Commission (NSSC), South Korea's nuclear regulator.

Hanul, Largest Nuclear Power Plant in the World

Once Shin-Hanul-2 is connected to the grid, Hanul will become one of only two sites in the world hosting eight reactors (the other one being Bruce in Ontario, Canada). The global average number of reactors per site is 2.5 while the Korean average is double with five reactors per site—seven for Hanul, six for Hanbit, five each for Kori and Wolsong, and two for Saeul.

The total installed capacity of the eight Hanul units will be 8.65 GW net, larger than that of Bruce with 6.36 GW and 1.5 times larger than Europe's largest nuclear site, Zaporizhzhya in Ukraine with six units totaling 5.7 GW (currently occupied by the Russian army). As Ukrainian nuclear facilities have been militarily targeted, there is a growing concern in the South Korean society about the risk of densely located nuclear reactors being attacked since the Korean Peninsula still technically remains in a state of war between North and South Korea with an armistice agreement since 1953.[555]

Increased Nuclear Power Generation

According to IAEA-PRIS, in 2022, nuclear power generation increased by 11.3 percent to 167.5 TWh net and provided 30.4 percent of the electricity in the country, up 2.4 percentage points from 2021.[556]

The increase of the nuclear power generation in 2022 compared to the previous year was mainly due to increased performance of some reactors as well as the start-up of Shin-Hanul-1.The load factor of Hanbit-5 increased from 18.7 percent in 2021 to 99.8 percent in 2022, generating an additional 7 TWh.[557] Hanbit-5 was back online after experiencing a prolonged outage from

554 - *Yonhap News Agency,* "울산 원자력발전소 운영·건설 전담할 '새울원전본부' 출범" ["The 'Saeul Nuclear Power Plant Headquarters' established to be in charge of operating and constructing nuclear reactors in Ulsan"], 3 January 2017 (in Korean), see https://www.yna.co.kr/view/AKR20170103072600057, accessed 1 July 2023.

555 - *Segye Ilbo,* "원전 위협·드론 공격·가짜 뉴스... '하이브리드戰' 대비해야 [심층기획–우크라전쟁 1년과 한국]" ["Nuclear threat, drone attack, fake news... prepare for 'Hybrid War.' [A feature story - 1 year of the Ukraine War and Korea]"], 21 February 2023 (in Korean), see https://m.segye.com/view/20230220513878, accessed 26 August 2023.

556 - According to the Korean Statistical Information Service (KOSIS), nuclear power provided 176 TWh in 2022 versus 158 TWh in 2021. Nuclear power provided 29.6 percent of the electricity in 2022 versus 27.4 percent in 2021; see KOSIS, "에너지원별 발전량 현황" ["Power Generation by Energy Source"], Korean Statistical Information Service, Undated, see https://www.index.go.kr/unity/potal/main/EachDtlPageDetail.do?idx_cd=1339, accessed 30 September 2023.

557 - IAEA-PRIS, "Country Statistics—Hanbit 5", Power Reactor Information System, International Atomic Energy Agency, Updated 30 September 2023, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=402, accessed 1 October 2023.

26 October 2020 to 22 October 2021 due to safety issues related to an automatic trip of the reactor and "faulty welding" of the reactor vessel head penetrations.[558]

The new APR-1400 reactor Shin-Hanul-1 contributed 3 TWh to the generation increase in 2022. The seventh Hanul unit was first connected to the grid on 9 June 2022 after almost 10 years of construction starting on 10 July 2012 with years of delay.

Hanbit-4, which was in long-term outage (LTO) since May 2017 finally restarted on 11 December 2022. Local residents, NGOs, and nearby city councils were opposed to the restart because they claimed that the safety reviews and repair work on the 140 voids identified in the concrete containment walls and corrosion on containment liner plates were not thorough enough. However, the national nuclear regulator, the Nuclear Safety and Security Commission (NSSC), decided to grant permission to restart without consultation of the local people which is not legally required in South Korea.[559]

KEPCO's Financial Crisis

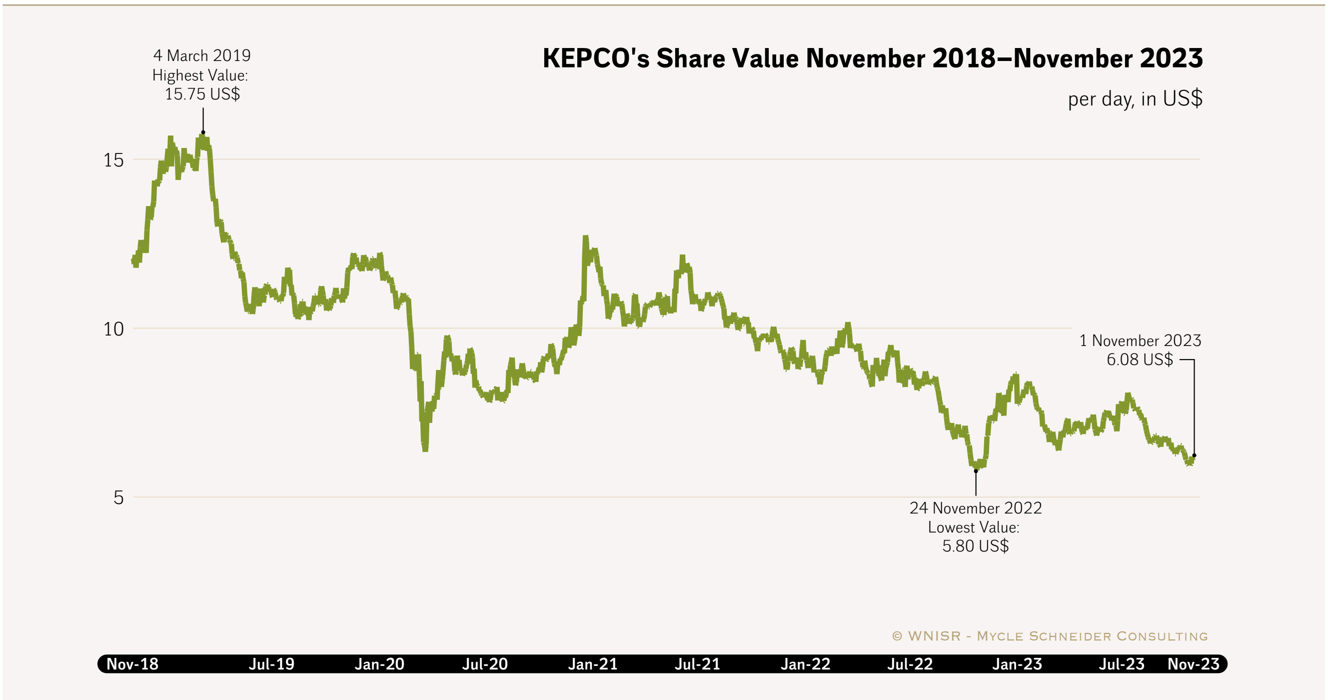
In 2022, the state-owned company KEPCO, builder, owner, and operator of South Korea's nuclear power plants, filed a record operating loss of KRW32.6 trillion (US$$_{2022}$25.2 billion) and its net debt jumped by 32 percent to reach unprecedented KRW192.8 trillion (US$149 billion). KEPCO's CEO resigned over the results in May 2023. Under the principle of "selling all available properties" KEPCO announced the sale of its Seoul headquarters building in the heart of Seoul, along with 44 buildings owned by the company.[560] Investor trust has been eroding for a while. KEPCO stocks lost 70 percent of their value over the past seven years (see Figure 46). The downward trend did not change following a new, ultra pro-nuclear administration taking office in mid-2022.

558 - *Yonhap News Agency*, "지난해 한빛5호기 자동정지는 작업자 실수 탓…" 밸브 안열어놔"" ["The automatic shutdown of Hanbit-5 last year was due to a worker's mistake… 'Didn't open the valve'"], 22 October 2021 (in Korean), see https://www.yna.co.kr/view/AKR20211022076800017, accessed 17 July 2023; and NSSC, "The NSSC Starts Investigation on Reactor Trip of Hanbit Unit 5 During Periodic Inspection", Press Release, Nuclear Safety and Security Commission, 26 October 2020, see https://www.nssc.go.kr/ajaxfile/FR_SVC/FileDown.do?GBN=X01&BOARD_SEQ=1&SITE_NO=3&BBS_SEQ=45966&FILE_SEQ=1; also NSSC, "NSSC Approved Resumption of Hanbit Unit 5", Press Release, 22 October 2021, see https://www.nssc.go.kr/ajaxfile/FR_SVC/FileDown.do?GBN=X01&BOARD_SEQ=1&SITE_NO=3&BBS_SEQ=46062&FILE_SEQ=1; both accessed 1 October 2023.

559 - NSSC, "NSSC Approved Criticality of Hanbit Unit 4", Press Release, 9 December 2022, see https://www.nssc.go.kr/ajaxfile/FR_SVC/FileDown.do?GBN=X01&BOARD_SEQ=1&SITE_NO=3&BBS_SEQ=46164&FILE_SEQ=1, accessed 1 October 2023; and *The Hankyoreh*, "'부실' 한빛4호기 5년 만에 재가동…'140개 구멍' 돔 안전성 논란 여전" ["Hanbit-4 restarts after 5 years… '140 holes' containment safety controversy remains"], 11 December 2022 (in Korean), see https://www.hani.co.kr/arti/society/environment/1071134.html, accessed 20 July 2023.

560 - KEPCO, "Korea Electric Power Corporation and Its Subsidiaries—Consolidated Financial Statements for the years ended December 31, 2022 and 2021", Korea Electric Power Corporation, 13 March 2023, see https://home.kepco.co.kr/kepco/EN/ntcob/list.do?boardCd=BRD_000259&menuCd=EN030201; and *The Korea Herald*, "Kepco chief offers to resign amid deficit woes", 12 May 2023, see https://news.koreaherald.com/common/newsprint.php?ud=20230512000550; both accessed 30 September 2023.

Figure 46 · Korea Electric Power Corporation Stock Value



Source: Yahoo Finances, 2023

Nuclear Policy Under the Moon and Yoon Administrations

In June 2022, President Yoon and his administration pledged KRW1,000 billion (US$$_{2022}$774 million) in investments by 2025 "to rebuild" the industry, a sum that corresponds to 0.5 percent of KEPCO's net debt.[561] The current administration also means to allocate KRW400 billion (~US$$_{2022}$310 million) for the development of SMRs.[562]

On 25 July 2023, the Ministry of Environment (ME) announced first estimates of the country's 2022-greenhouse gas emissions (GHG). In the press release, ME attributed the year-on-year decrease in GHG emissions to Yoon's energy policy changes, quoting nuclear power among the main drivers[563].

However, the nuclear production increase was not related to policy changes. The differences between the Moon and Yoon administrations' nuclear policy consist in the implementation of lifetime extensions of existing reactors (Yoon) or not (Moon) and the possible launch of new reactor constructions beyond the ones already underway (Yoon) or not (Moon). Therefore, the differences did not influence nuclear power generation between 2021 and 2022.

561 - *NEI Magazine*, "South Korean President affirms support for nuclear", 24 June 2022, see https://www.neimagazine.com/news/newssouth-korean-president-affirms-support-for-nuclear-9797716/, accessed 9 September 2022.

562 - *NEI Magazine*, "South Korea plans 30% nuclear share by 2030", 7 July 2022, see https://www.neimagazine.com/news/newssouth-korea-plans-30-nuclear-share-by-2030-9832470/, accessed 9 September 2022.

563 -ME, "2022년 온실가스 잠정배출량 전년보다 3.5% 감소한 6억 5,450만톤 예상" ["2022 GHG emission estimates are expected to be 654.5 million tons, 3.5% decrease from previous year"], Ministry of Environment, Government of South Korea, 25 July 2023 (in Korean) accessed 16 July 2023.

Moon's nuclear phaseout policy established in 2017 is often misrepresented. For example, South Korea's country profile-page on the World Nuclear Association (WNA) website states that "the previous government's policy was to phase out nuclear power over a period of 40 years".[564] In reality, Moon's nuclear policy guaranteed the design lifetime—without extension—of the existing reactors and those under construction, and it planned no additional reactors after Saeul-3 and -4. Because the design lifetime of Saeul-3 and -4 is 60 years, the planned complete nuclear "phaseout" in South Korea was scheduled around 2085 considering that Saeul-4 was planned to be completed by 2025. Compared to the nuclear phaseout policy in Germany in 2023 and in Taiwan by 2025, the South Korean policy was in fact rather a nuclear program limitation than a phaseout strategy.

It will not be before June 2025 that Yoon's pro-nuclear policy approach could substantially influence actual nuclear power generation, as that is when the oldest operational reactor Kori-2 is scheduled to be restarted. Kori-2 was shut down on 8 April 2023 upon expiration of its 40-year license and is to undergo inspection and refurbishment work over several years to allow restart and lifetime extension.[565]

Proactive Lifetime Extension

In order to prevent a reactor from being out of operation for a long time due to safety reviews and refurbishment for lifetime extension, the NSSC amended the Enforcement Decree of the Nuclear Safety Act to the effect that the operator can submit a safety assessment report for lifetime extension five to ten years—rather than two to five years—prior to the operating license's expiration date.[566] With the amendment, the number of nuclear reactors whose lifetime extension are likely to be applied for during the Yoon administration's 5-year term (10 February 2022–10 February 2027) increased from 10 to 18 reactors.

More Newbuild Planned

The incumbent Yoon administration announced its intent to revive the previously abandoned construction of the 9th and 10th reactors at the Hanul site, Shin-Hanul-3 and -4. The two new units are scheduled to be completed by October 2032 and 2033.[567] The Tenth Basic Plan for Long-term Electricity Supply and Demand (BPE, 2022~2036) was issued in January 2023; it included the construction of the two Shin-Hanul units.

564 - WNA, "Nuclear Power in South Korea", World Nuclear Association, Updated September 2023, see https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx, accessed 1 October 2023.

565 - *Yonhap News Agency*, "S. Korea suspends operation of Kori-2 reactor for permission renewal", as published by *The Korea Herald*, 9 April 2023, see https://www.koreaherald.com/view.php?ud=20230409000048, accessed 1 October 2023.

566 - *NEWSIS*, "원안위, 원전 '수명연장' 신청 기간 5~10년으로 확대…안전성은 우려 ["Nuclear Safety and Security Commission Expands the Application Period for 'Lifetime Extension' of Nuclear Power Plants to 5-10 Years...Safety is a concern"]", 15 September 2022 (in Korean), see https://newsis.com/view/?id=NISX20220915_0002014153&cID=10401&pID=10400, accessed 25 August 2023.

567 - KPX, "2023년도 2분기 발전소 건설사업 추진현황" ["Progress of Power Plant Construction Project in Q2 2023"], Korea Power Exchange, 21 August 2023, see https://www.kpx.or.kr/board.es?mid=a10403040000&bid=0040&act=view&list_no=70293; and MOTIE, "제10차 전력수급기본계획(2022~2036) 확정" ["The 10th Basic Plan for Electricity supply and demand (2022-2036) is confirmed"], Ministry of Trade, Industry and Energy, Government of South Korea, 12 January 2023 (in Korean), see https://www.korea.kr/briefing/pressReleaseView.do?newsId=156547521; both accessed 1 October 2023.

Table 12 · 2022, 2030 and 2036 Electricity Mix in South Korea

Plan	Production / Share of Electricity	Nuclear	Coal	LNG	NRE[(a)]	Hydrogen & Ammonia	Other	Total
Actual Electricity Mix in 2022	TWh	176.1	193.2	163.6	53.2	-	8.4	594.4
	Share	29.6%	32.5%	27.5%	8.9%	-	1.4%	100%
Electricity Mix Target for 2030	TWh	201.7	122.5	142.4	134.1	13.0	8.1	621.8
	Share	32.4%	19.7%	22.9%	21.6%	2.1%	1.3%	100%
Electricity Mix Target for 2036	TWh	230.7	95.9	62.3	204.4	47.4	26.6	667.3
	Share	34.6%	14.4%	9.3%	30.6%	7.1%	4.0%	100%

Sources: WNISR, based on data from KOSIS and MOTIE, 2023[568]

(a) **NRE**: New and Renewable Energy. New energy in South Korea includes Integrated Gasification Combined Cycle (IGCC) and fuel cells.

As shown in Table 12, the nuclear share in the electricity mix is planned to continue to increase up to 34.6 percent in 2036. The share of fossil fuels in the 2030 electricity mix of the 10th BPE by the Yoon administration is not very different from the share of fossil fuels in the previous governmental plan (the 2021 Nationally Determined Contribution or NDC) of Moon's administration. However, Yoon's administration decreased the 2030-renewable-share target from 30.2 percent to 21.6 percent as the result of increasing the nuclear share from 23.9 percent to 32.4 percent.

South Korea was the 8th largest electricity producer in the world in 2022, surpassing Germany since 2020.569 It is remarkable that the country generated more electricity than Germany, considering that Germany has a 1.6 times larger population. Especially the industrial and service sectors have kept increasing their consumption and represent disproportionate shares of overall consumption. While in most industrialized countries, electricity consumption has stagnated or declined over the past decade or so, South Korea has seen a steady increase over most of this period. In April 2023, Germany completed its nuclear phaseout. Under the current policy, South Korea would rely on nuclear power generation at least until close to the end of the 21st Century.

Yoon Administration in Search of New Sites

On 18 July 2023, the Yoon administration announced that it would develop the 11th BPE for 2024–2038 early. Also, MOTIE said that the key direction of the next BPE would be the increase of nuclear power capacity in the framework of its climate change policy, in particular to cover new electricity demand from industry, such as the expansion of a semiconductor cluster in Yongin.570 If new nuclear capacity was included in the 11th BPE, it would be the first time since the 7th BPE in 2015, which featured the plan for Shin-Hanul-3 & -4.

568 - KOSIS, "에너지원별 발전량 현황" ["Power Generation by Energy Source"], Korean Statistical Information Service, 2023, see https://www.index.go.kr/unity/potal/main/EachDtlPageDetail.do?idx_cd=1339, accessed 15 July 2023; and MOTIE, "제10차 전력수급기본계획(2022~2036) 확정" ["The 10th Basic Plan for Electricity supply and demand (2022-2036) is confirmed"], Ministry of Trade, Industry and Energy, Government of South Korea, 12 January 2023, op. cit.

569 - Energy Institute, "Statistical Review of World Energy", June 2023, see https://www.energyinst.org/statistical-review, accessed 1 October 2023.

570 - *Yonhap News Agency*, "'새 원전' 도입논의 본격화...11차 전력수급계획 수립 착수" ["Discussions on the introduction of 'new nuclear power plants' started...Establishment of the 11th BPE kicked-off"], 18 July 2023 (in Korean), see https://www.yna.co.kr/view/AKR20230718044800003?input=1195m, accessed 26 August 2023.

Two further sites were envisaged for nuclear newbuild before. Samcheok in Gangwon Province and Yeongdeok in North Gyeongsang Province were officially designated as greenfield sites for nuclear reactor construction in 2012.[571] However, following the Fukushima catastrophe, local opposition to the project grew. Consequently, Samcheok residents organized a local referendum in October 2014, resulting in 84.9 percent voting against the project.[572] The people in Yeongdeok also organized a local referendum in November 2015, resulting in 91.7 percentage of votes against the new nuclear reactors, but it was invalidated as voter turnout at 32.5 percent remained just below the legally required one third of eligible voters.[573] While the consultations had no legal weight, during the Moon administration, due to the long civil movement against the plan, the site designations were officially cancelled in 2019 for Samcheok and 2021 for Yeongdeok.

Therefore, the Yoon administration likely needs to find one or several new sites. Local people in Ullu-gun in Ulsan where the Saeul nuclear plant is located are already divided over new nuclear construction. Social conflicts among the local people over nuclear power plant projects are likely to erupt again in South Korea.[574]

Efforts to Boost Nuclear Exports

In August 2023, the South Korean Financial Services Commission boosted financing support for exporting companies—including the nuclear power industry with an unknown share—by around 50 percent to a total of KRW23 trillion (~US$18 billion).[575]

This is only the latest in a number of actions translating the government's efforts to help the ailing export and nuclear sectors. KEPCO is still in the course of finalizing its only foreign construction project so far, i.e., the delivery of four reactors to the United Arab Emirates (UAE). The Barakah project was supposed to demonstrate the feasibility of the implementation on-time on-budget of a nuclear power plant construction in a newcomer country. The project is three years behind schedule and the extent of cost overrun is unknown.

Further reactor export projects by the Korean nuclear industry are fragilized by an ongoing litigation in a case brought against KHNP by Westinghouse in October 2022. Westinghouse claims KHNP requires U.S. approval to export its APR-1400 technology and infringed its intellectual property rights by failing to do so. The case is also being reviewed by the Korean Commercial Arbitration Board since August 2023, as previous negotiation efforts failed to

571 - MOTIE, "제 경북 영덕 · 강원 삼척 원전 예정구역 최종 확정" ["Final confirmation of planned nuclear power plant sites in Yeongdeok, Gyeongbuk and Samcheok, Gangwon Province"], Ministry of Trade, Industry and Energy, Government of South Korea, 14 September 2012 (in Korean), see https://www.motie.go.kr/motie/ne/motienewse/Motienews/bbs/bbsView.do?bbs_seq_n=155113971&bbs_cd_n=2, accessed 26 August 2023.

572 - Kim Se-jeong, "Samcheok vows to nullify nuclear plant plan", *The Korea Times*, 10 October 2014, see https://www.koreatimes.co.kr/www/nation/2023/10/113_166103.html, accessed 1 October 2023.

573 - Kim Se-jeong, "Referendum on nuke plant turns invalid", *The Korea Times*, 13 November 2015, see https://www.koreatimes.co.kr/www/nation/2023/09/113_190944.html, accessed 1 October 2023.

574 - *Kyunghyang Shinmun*, " '후쿠시마 오염수로 난리인데' 울산은 신규 원전유치 놓고 '시끌'" ["Fukushima's contaminated water is making a fuss. Ulsan is making a fuss over attracting new nuclear power plants"], 31 August 2023 (in Korean), see https://www.khan.co.kr/national/national-general/article/202308311540001, accessed 26 August 2023.

575 - Jihoon Lee, "South Korea to grant 23 trln won in financing support for exporters", *Reuters*, 16 August 2023, see https://www.reuters.com/markets/asia/south-korea-grant-23-trln-won-financing-support-exporters-2023-08-16/, accessed 29 August 2023.

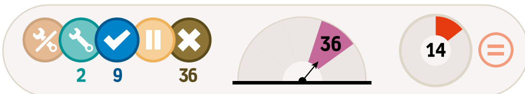
settle the dispute. Damages claimed by either side amount to several hundred million US dollars.

On 25 August 2022, six months into the Ukraine invasion, KEPCO with its subsidiary KHNP and Rosatom with its subsidiary Atomstroyexport JSC signed a US$2.25-billion contract to provide around 80 buildings and structures at four units of El Dabaa nuclear power plant and supply related equipment and materials. Rosatom is the contractor for the El Dabaa plant. No information on financial aspects is publicly available concerning Barakah and El Daaba. KEPCO's 2022-Annual Report indicates:

> The contracts with purchasers state that the disclosure of information related to UAE and Egypt Eldaba nuclear power plant construction projects such as contract date, contractual completion date, rate of progress, unbilled construction, impairment losses, etc. is not allowed without consent from the purchasers. The purchasers did not agree to disclose such information. Accordingly, the [KEPCO] Group did not disclose such information...[576]

While the current administration has clearly set a different political agenda for nuclear power than its predecessor, the outlook remains highly uncertain—as well in the country as concerning the country's overseas ambitions—as the dire financial state of the flagship company KEPCO leaves little or no room for major investment expansions.

UNITED KINGDOM FOCUS



As of mid-2023, the United Kingdom (U.K.) operated nine reactors, two less than the previous edition of the WNISR, with the closure of the two units at Hinkley Point B on 6 July 2022 (B-2) and 1 August 2022 (B-1) respectively. This follows the closure of the two reactors at Hunterston in November 2021 and January 2022, and two units at Dungeness officially closed in June 2021 (last power generation in 2018, see Figure 47). In total, 36 nuclear reactors have been closed in the U.K., the second largest number of any country behind the United States (see Decommissioning Status Report). This includes all 26 Magnox reactors, two fast breeders, one small Steam-Generating Heavy Water Reactor (SGHWR) and seven Advanced Gas Reactors (AGRs). There are now 5.8 GW of nuclear capacity in operation, with 7.8 GW awaiting decommissioning.

In 2022, nuclear plants generated 47.7 TWh, an increase for the first time in six years, producing 14.7 percent of electricity, down from a maximum share of 28 percent in 1997.[577]

The electricity mix in the U.K. has changed rapidly over the past decades, as seen in Figure 48. The most significant trend was the rapid increase in the use of renewable energy—from 2.8 percent at the turn of the century to 41.5 percent in 2022.[578] The total contribution of

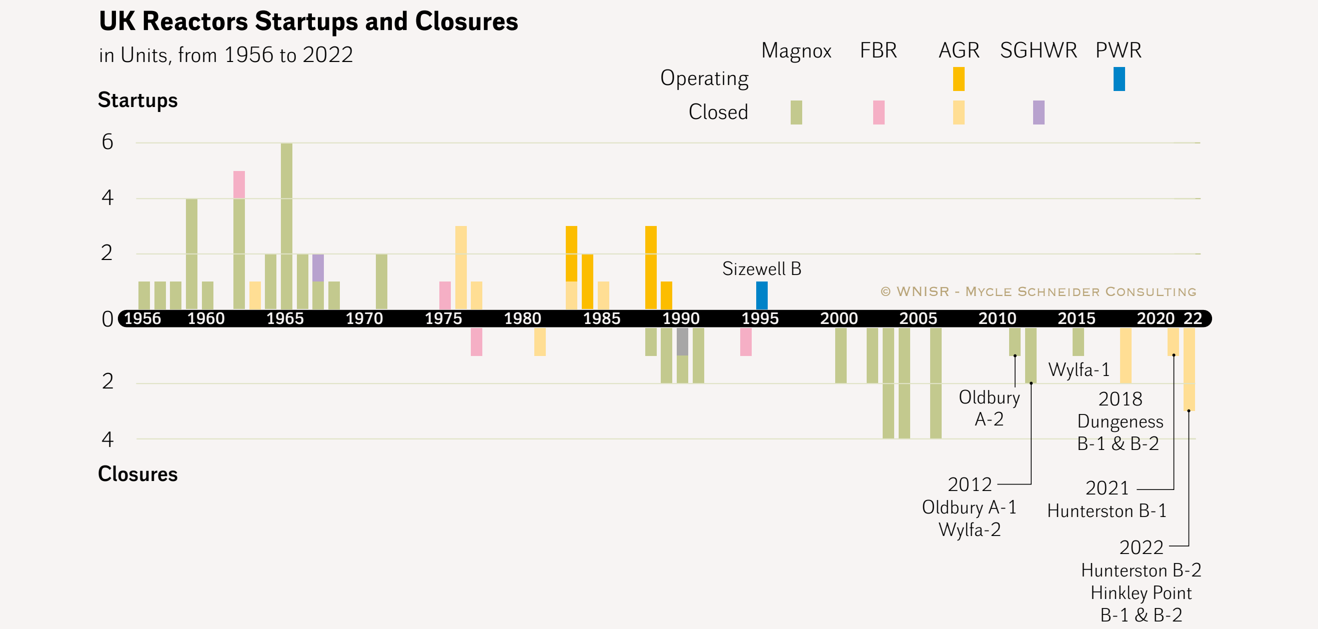
576 - KEPCO, "Korea Electric Power Corporation and its Subsidiaries—Consolidated Financial Statements for the years ended December 31, 2022 and 2021", March 2023, op. cit.

577 - Department for Energy Security & Net Zero and National Statistics, "Energy Trends—UK, January to March 2023", Statistical Release, U.K. Government, 29 June 2023, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1166039/Energy_Trends_June_2023.pdf, accessed 5 July 2023.

578 - Department for Energy Security & Net Zero, "National Statistics—Digest of UK Energy Statistics – Electricity fuel use, generation and supply", U.K. Government, Updated 27 July 2023, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1174143/DUKES_5.6.xlsx, accessed 27 July 2023.

renewable energy to the power mix—including biomass and hydro—saw a significant increase of 1.9 percentage points over the previous year due to 3.8 GW of new wind and solar capacity.

Figure 47 • U.K. Reactor Startups and Closures



Source: WNISR with IAEA-PRIS and EDF Energy, 2022-2023

Type of Reactors:

AGR: Advanced Gas Reactors; **FBR:** Fast Breeder Reactor; **PWR:** Pressurized Water Reactor; **SGHWR:** Steam Generating Heavy Water Reactor

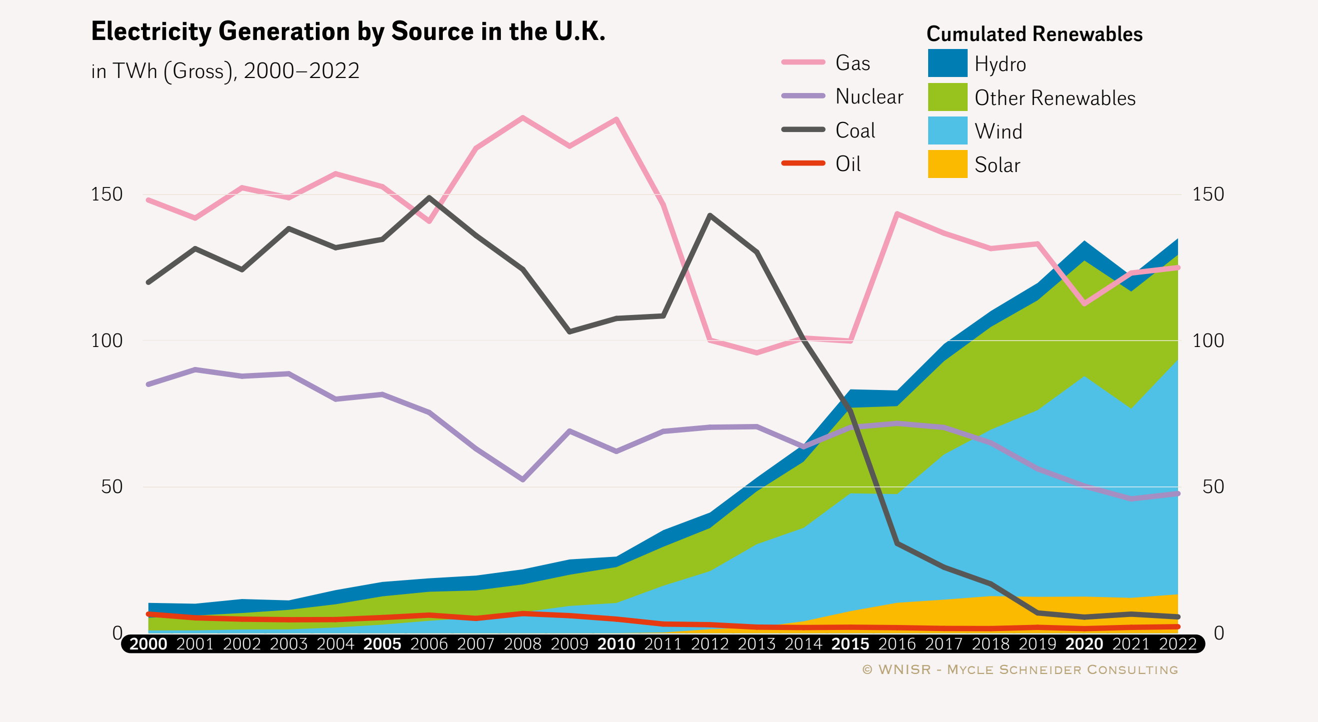
While Great Britain—including England, Scotland, and Wales, but not Northern Ireland—has left the E.U. Internal Energy Market, electricity trade continues with E.U. Member States. Despite Brexit, electricity trade is increasing as new interconnectors become operational. Most recently, in 2021, a new connection was made with Norway, the North Sea Link, a 1.4 GW ~720 km cable, which follows on the back of new interconnectors to France in 2020 and Belgium in 2019.[579] As of 2022, there were seven cables with a total capacity of 7.4 GW, and while these allow power to flow both ways, the British market has historically been a net importer.[580] However, due to the ongoing generic problems in the French nuclear fleet, the falling production of electricity in France led to the U.K. becoming a net exporter of electricity for the first time in forty years in 2022 with a positive trade balance of 5.3 TWh.[581]

579 - National Grid Group, "Interconnectors", 2023, see https://www.nationalgrid.com/national-grid-ventures/interconnectors-connecting-cleaner-future, accessed 11 September 2023.

580 - Department for Business, Energy & Industrial Strategy, "Electricity interconnectors in the UK since 2010", Special Article, Energy Trends Collection, U.K. Government, 30 June 2022, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1086528/Electricity_interconnectors_in_the_UK_since_2010.pdf, accessed 11 September 2023.

581 - Department for Energy Security & Net Zero and Department for Business, Energy & Industrial Strategy, "Chapter 5: Electricity", in "Digest of UK Energy Statistics (DUKES)", U.K. Government, Updated 27 July 2023, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1174357/DUKES_2023_Chapter_5.pdf, accessed 11 September 2023.

Figure 48 · Electricity Generation by Source in the U.K., 2000–2022



Source: U.K. Government, DUKES 2023[582]

Closure of the Advanced Gas-cooled Reactors (AGRs)

Managing reactors as they age is a constant problem for any technology design, and the AGRs are no exception. In recent years, issues with the core's graphite moderator bricks have raised concerns. Keyway Root Cracks (KWRC) were unexpectedly found at the (now closed) Hunterston B reactors in 2016. This can lead to the degradation of the keying system, a vital component that houses the fuel, the control rods, and the coolant (CO_2). Their cracking or distortion could impact the control rods' insertion or the coolant's flow. There are also issues of graphite erosion, and several of the AGRs are close to the erosion limits that the Office for Nuclear Regulation (ONR) has set. ONR has said, "most of the AGRs will have their life limited by the progression of cracking", as replacing the graphite bricks is impossible.[583]

Besides the small unit at Windscale/Sellafield, 14 AGRs were built (see Figure 47), operating at seven stations. Until mid-2021, Hinkley Point B and Hunterston B were due to operate until 2023, while Dungeness B was due to operate until 2028. However, by early 2022, the situation

582 - Department for Energy Security & Net Zero, "National Statistics—Digest of UK Energy Statistics – Electricity fuel use, generation and supply", U.K. Gouvernment, Updated 27 July 2023, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1174143/DUKES_5.6.xlsx, accessed 27 July 2023.

583 - ONR, "Operating power stations—Graphite core ageing", Office for Nuclear Regulation, Updated 13 April 2023, see https://www.onr.org.uk/civil-nuclear-reactors/graphite-core-ageing.htm, accessed 11 September 2023.

had dramatically changed, with EDF officially closing Dungeness B-1 and -2 in June 2021, Hunterston B in January 2022, and then Hinkley Point B in July/August 2022.[584]

Hartlepool and Heysham A were due to close in 2024; Electricité de France (EDF) delayed closure by two years in March 2023,[585] but the Office for Nuclear Regulation (ONR) has said that while a plant life extension did not require formal approval, EDF would need to produce updated safety cases for the plants, which will be assessed by the regulator.[586] In late 2021, the closure of the last two units (Torness and Heysham B), previously due in 2030, was brought forward to 2028.[587] (See Table 13)

Table 13 · Status of U.K. EDF AGR Nuclear Reactor Fleet (as of 1 July 2023)

Reactor	Net Capacity (MW)	Grid Connection	Closure/ Expected Closure
Dungeness B-1 **Dungeness B-2**	545 545	03/04/1983 29/12/1985	Closed June 2021 (Last power in 2018)
Hartlepool A-1 **Hartlepool A-2**	590 595	01/08/1983 31/10/1984	March 2026
Heysham A-1 **Heysham A-2**	485 575	09/07/1983 11/10/1984	March 2026
Heysham B-1 **Heysham B-2**	620 620	12/07/1988 11/11/1988	March 2028
Hinkley Point B-1 **Hinkley Point B-2**	485 480	30/10/1976 05/02/1976	Closed July/August 2022
Hunterston B-1 **Hunterston B-2**	490 495	06/02/1976 31/03/1977	Closed November 2021 Closed January 2022
Torness-1 **Torness-2**	595 605	25/05/1988 03/02/1989	March 2028

Sources: EDF Energy, 2023

The decommissioning cost estimates for the AGRs have continued to rise, and according to the Parliament's Public Accounts Committee, costs "have almost doubled since March 2004, estimated at £23.5 billion [US$$_{2021}$32 billion] in March 2021, and there remains a significant risk that the costs could rise further." [588] In 2022 it was reported by the National Audit Office that the fund to manage the cost of decommissioning the AGRs had received a total of £11.8 billion (US$$_{2022}$14.5 billion), this included in 2020 £5.1 billion (US$$_{2020}$6.5 billion) from

584 - EDF, "EDF decides to move Dungeness B into defuelling phase", Press Release, 7 June 2021, see https://www.edfenergy.com/media-centre/news-releases/edf-decides-move-dungeness-b-defuelling-phase; and EDF, "Zero-carbon electricity generation ends at Hunterston B" Press Release, 7 January 2022, see https://www.edfenergy.com/media-centre/news-releases/zero-carbon-electricity-generation-ends-hunterston-b; also EDF, "Hinkley Point B power station", Undated, see https://www.edfenergy.com/energy/power-stations/hinkley-point-b; all accessed 11 September 2023.

585 - EDF Energy, "EDF confirms plans to keep turbines turning at Heysham 1 and Hartlepool power stations", Press Release, 9 March 2023, see https://www.edfenergy.com/media-centre/news-releases/edf-confirms-plans-keep-turbines-turning-heysham-1-and-hartlepool-power, accessed 17 March 2023.

586 - ONR, "EDF announces operating life extensions for Heysham 1 and Hartlepool", Office for Nuclear Regulation, 9 March 2023, see https://news.onr.org.uk/2023/03/edf-announces-operating-life-extensions-for-heysham-1-and-hartlepool/, accessed 9 March 2023.

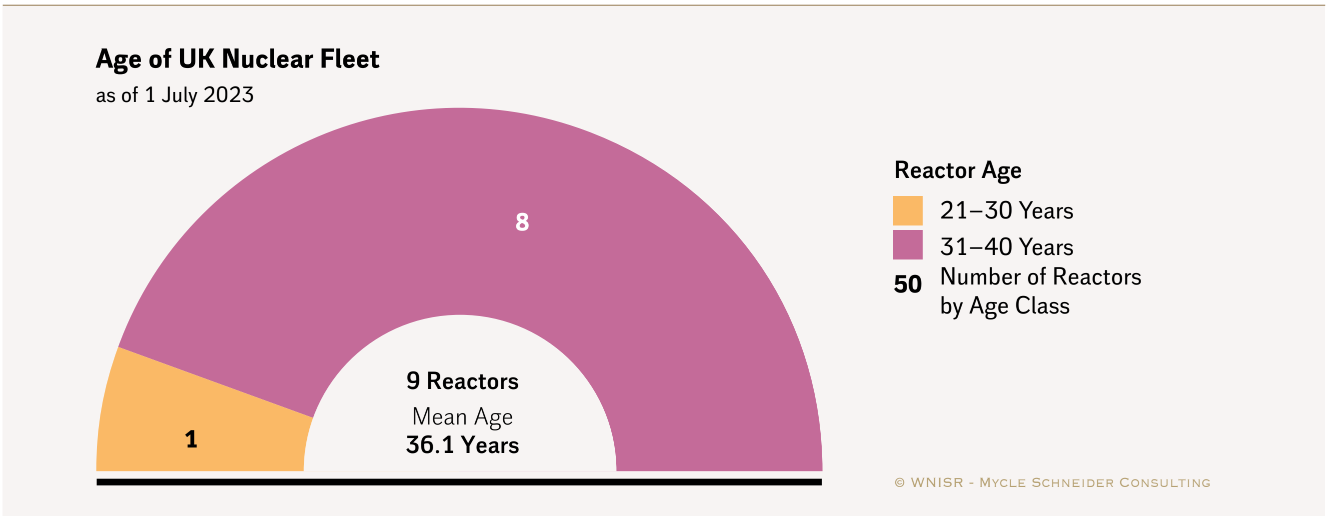
587 - EDF, "AGR lifetime reviews carried out", Press Release, 15 December 2021, see https://www.edfenergy.com/media-centre/news-releases/agr-lifetime-reviews-carried-out, accessed 17 June 2022.

588 - Committee of Public Accounts, "The Future of the Advanced Gas-cooled Reactors", HC 118, Third Report of Session 2022–23, House of Commons, 20 May 2022, see https://committees.parliament.uk/publications/22301/documents/165594/default/, accessed 11 September 2023.

the Treasury and from funds from the sale of British Energy. However, they also noted that the fund had requested a further £5.6 billion (US$$_{2022}$6.9 billion) from the Government, "due primarily to an increase in corporation tax rates to be paid by the Fund".[589]

The annual cost of decommissioning civil nuclear facilities covered by the Nuclear Decommissioning Authority for 2023–2024 is £4.13 billion (~US$$_{2023}$5.2 billion), of which £2.96 billion (~US$$_{2023}$3.7 billion) will be funded by the U.K. government and £1.17 billion (~US$_{2023}$$1.5 billion) from internally provided revenue previously generated from the industry.[590]

Figure 49 · Age Distribution of U.K. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2023

Pathways to Net Zero

The U.K. has set one of the world's most ambitious greenhouse gas emissions targets, committing to a 68 percent reduction from 1990 levels by 2030 and 78 percent by 2035[591] compared to a 48.7 percent reduction achieved in 2022.[592] The U.K. government has also committed to a zero-emission power sector by 2035. However, while it has reduced territorial emissions significantly (this does not include emissions associated with the production of

589 - NAO, "The decommissioning of the AGR nuclear power stations", Press Release, National Audit Office, 28 January 2022, see https://www.nao.org.uk/press-releases/the-decommissioning-of-the-agr-nuclear-power-stations/, accessed 15 October 2023.

590 - NDA, "Nuclear Decommissioning Authority: Business Plan 2023 to 2026", Nuclear Decommissioning Authority, U.K. Government, April 2023, see https://www.gov.uk/government/publications/nuclear-decommissioning-authority-business-plan-2023-to-2026/nuclear-decommissioning-authority-business-plan-2023-to-2026, accessed 11 September 2023; and NAO, "The Decommissioning of the AGR nuclear power stations", HC 1017, National Audit Office, Department for Business, Energy & Industrial Strategy, 28 January 2023, see https://www.nao.org.uk/wp-content/uploads/2022/01/The-decommissioning-of-the-AGR-nuclear-power-stations.pdf, accessed 6 November 2023.

591 - Department of Business, Energy & Industrial Strategy and Prime Minister's Office, "UK enshrines new target in law to slash emissions by 78% by 2035", Press Release, U.K. Government, 20 April 2021, see https://www.gov.uk/government/news/uk-enshrines-new-target-in-law-to-slash-emissions-by-78-by-2035, accessed 12 September 2023.

592 - Department for Energy Security & Net Zero and National Statistics, "2022 UK Greenhouse gas emissions, provisional figures", U.K. Government, 30 March 2023, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1147372/2022_Provisional_emissions_statistics_report.pdf, accessed 12 September 2023.

goods overseas which are excluded from UNFCCC calculations), there is still a considerable amount to do, if 2030 pledges are to be met.[593]

The Climate Change Committee (CCC), an independent body established to advise the government on meeting its climate commitments, produced a report in 2019 on how the U.K. can meet its Net Zero commitments.[594] Growing public pressure, particularly with large-scale mobilizations from Extinction Rebellion, as well as cross-party political support led to an adoption by the Government of an amendment of the 2008 Climate Change Act to require GHG emissions to be net zero by 2050, which entered into force on 27 June 2019.[595]

Interestingly, three out of five of the CCC's energy net zero scenarios featured just 5 GW of nuclear capacity by 2050, equating to completing Hinkley Point C and life-extending Sizewell B for 2035–2055. The remaining two scenarios featured 10 GW of nuclear capacity, which would require the completion of Sizewell C, plus two more similar sized power stations. The Committee concluded:[596]

> Renewables are cheaper than alternative forms of power generation in the U.K. and can be deployed at scale to meet increased electricity demand in 2050 - we therefore consider deep decarbonisation of electricity to be a Core measure.
>
> (…)
>
> Reducing emissions towards net-zero **will require** continued deployment of renewables and **possibly** nuclear power and other low-carbon sources such as carbon capture and storage and hydrogen, along with avoiding emissions by improving energy efficiency or reducing demand. [Emphasis added.]

The Committee recognizes renewables' economic and deployment advantages over nuclear power as the country moves toward a zero emissions economy.

In November 2020, the U.K. Government published a Ten-Point Plan for a Green Industrial Revolution, which included a specific point on "Delivering New and Advanced Nuclear Power".[597] This put forward milestones for the sector, including:

- 2021: Launch of Phase 2 of U.K. SMR design development;
- Mid 2020s: Hinkley Point C comes online;
- Early 2030s: First SMRs and Advanced Modular Reactor (AMR) demonstrator deployed in the U.K.

Then, in December 2020, the government published a long-awaited Energy White Paper. This stated that the aim was to "bring at least one large-scale nuclear project to the point of FID [Final Investment Decision] by the end of this Parliament [2024], subject to clear value

593 - Ibidem.

594 - Committee on Climate Change, "Net Zero—Technical Report", 2 May 2019, see https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf, accessed 12 September 2023.

595 - Sara Priestley, "Net Zero in the UK", Briefing Paper No. CBP8590, House of Commons Library, December 2019, see https://researchbriefings.files.parliament.uk/documents/CBP-8590/CBP-8590.pdf, accessed 12 September 2023.

596 - Committee on Climate Change, "Net Zero Technical report", 2 May 2019, op. cit.

597 - U.K. Government, "The Ten Point Plan for a Green Industrial Revolution", November 2020, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf, accessed 12 September 2023.

for money and all relevant approvals."[598] In an accompanying press statement, the government said it would begin negotiations with EDF on Sizewell C.[599] However, the approval requires a "value-for-money" hurdle to be passed, which is likely to be challenging given the current economics of nuclear vs. renewables.

The government announced in its Energy Security Strategy published in April 2022 that "a new government body, Great British Nuclear [GBN], will be set up immediately to bring forward new projects, backed by substantial funding," and it would "launch the £120 million [~US$$_{2022}$148 million] Future Nuclear Enabling Fund this month."[600] The nuclear fund had already been announced in the spending review of October 2021,601 and GBN was not launched before July 2023. Despite several "mini-announcements", there was no new commitment to government funding in the strategy. "I was expecting this to be bad, but not as bad as it was" one industry source told *Nuclear Intelligence Weekly*.[602] The main details of the "new" plan were:[603]

- To increase the deployment of nuclear power of up to 24 GW of capacity by 2050.
- To take a project to the final investment decision in this parliament, by 2024 (Sizewell C).
- Two further projects, including SMRs, are to be discussed in the next Parliament (scheduled for January 2025–2029).

The Government further outlined a plan for the development of four additional nuclear projects by 2030:

- A selection process in 2023 for further U.K. projects, with the goal to enable a potential government award of support as soon as possible, including (but not limited to) the Wylfa site. However, as with existing policy, "any projects would be subject to a value for money assessment, all relevant approvals and future spending reviews."
- In contrast to other onshore technologies, the government has said it will "work with the regulators to understand the potential for any streamlining or removing duplication from the consenting and licensing of new nuclear power stations."
- The government will "develop an overall siting strategy for the long term" targeted at eight designated nuclear sites: Hinkley, Sizewell, Heysham, Hartlepool, Bradwell, Wylfa, Oldbury and Moorside.

598 - BEIS, "Energy White Paper – Powering our Net Zero Future", CP 337, Presented to Parliament by the Secretary of State for Business, Energy and Industrial Strategy, December 2020, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf, accessed 12 September 2023.

599 - BEIS, "Government sets out plans for clean energy system and green jobs boom to build back greener", Press Release, Department for Business, Energy & Industrial Strategy, U.K. Government, 14 December 2020, see https://www.gov.uk/government/news/government-sets-out-plans-for-clean-energy-system-and-green-jobs-boom-to-build-back-greener, accessed 4 May 2021.

600 - BEIS and Prime Minister's Office, "Major acceleration of homegrown power in Britain's plan for greater energy independence", Press Release, Department for Business, Energy & Industrial Strategy, U.K. Government, 6 April 2022, see https://www.gov.uk/government/news/major-acceleration-of-homegrown-power-in-britains-plan-for-greater-energy-independence#:~:text=The%20government%E2%80%99s%20British%20Energy%20Security,by%202030%20being%20low%20carbon, accessed 12 September 2023.

601 - U.K. Government, "Autumn Budget and Spending Review 2021 - A stronger economy for the British people", HC 822, October 2021, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1043688/Budget_AB2021_Print.pdf, accessed 12 September 2023.

602 - Stephanie Cooke and Phil Chaffee, "Latest", *Nuclear Intelligence Weekly*, 8 April 2022.

603 - U.K. Government, "British Energy Security Strategy", Policy Paper, Updated 7 April 2022, see https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy, accessed 12 September 2023.

In July 2022, the High Court ruled that the U.K. Government's Net Zero strategy was unlawful and resulted in the government agreeing to revise its plans by the end of March 2023. The case was brought by NGOs Friends of the Earth, Good Law Project, and Client Earth, who argued that the Government did not meet its obligations under Sections 13 and 14 of the Climate Change Act of 2008 to enable Parliament to evaluate how the government intends to achieve its carbon budgets.[604]

In response to the July 2022 High Court ruling, the U.K. Government launched its 'Powering Up Britain' policies on 30 March 2023.[605] The Prime Minister was photographed at Culham, the centre of U.K. Fusion, for the launch of the 'Powering Up Britain' strategy. Much of the media focus on the launch surrounded the lack of sufficient ambition and funding for many low-cost and proven decarbonization policies and the more controversial aspects of carbon capture and storage (CCS) to compensate for additional oil and gas licenses and SMRs. The strategy stated that Great British Nuclear will decide on the leading SMR technologies by Autumn 2023.

In the Government's March 2023 budget, it was announced that they would seek to reclassify nuclear energy as environmentally sustainable in its green taxonomy. It was said that this was designed to "encourage private sector investment into our nuclear programme."[606]

On 18 July 2023, GBN was finally launched, and the statement announced that "a massive revival of nuclear energy gets underway today" and that "Energy Security Secretary Grant Shapps will today announce how GNB will drive the rapid expansion of new nuclear power plants in the U.K. at an unprecedented scale and pace." There were two main elements of the launch: Firstly, the announcement of a competition to get support for the construction of SMRs and the award of £157 million (~US$199 million) of grant funding. This includes £77 million (~US$97.5 million) for businesses to accelerate advanced nuclear designs and £58 million (~US$73 million) for further development of a new generation of SMRs that operate at higher temperatures—with three winning projects announced—and £22 million (~US$28 million) from the Nuclear Fuel Fund, allocated to eight new fuel fabrication facilities.[607] The level of funding, while politically relevant, will not significantly contribute to the overall development costs. In July 2023, the Parliament's Science, Innovation and Technical Committee published a report reviewing the Government's nuclear plans. The Committee is largely supportive of nuclear power and the Government's objective of having 24 GW of nuclear by 2050 but strongly questions the Government's strategy to meet the goal. In particular, the Committee asks the Government to clarify the role of Great British Nuclear beyond initially supporting SMRs and how it will engage with any projects beyond Sizewell C.[608]

604 - Client Earth, "We've won our case against the UK Government's inadequate net zero strategy", Press Release, 19 July 2022, see https://www.clientearth.org/latest/latest-updates/news/clientearth-are-suing-the-uk-government-over-its-net-zero-strategy/; and High Court of Justice, "Approved Judgment", Case Nos. CO/126/2022, CO/163/2022 and C/199/2022, Administrative Court, Royal Courts of Justice, 18 July 2022, see https://www.bailii.org/ew/cases/EWHC/Admin/2022/1841.pdf; both accessed 12 September 2023.

605 - Department for Energy Security and Net Zero, "Powering up Britain", Policy Paper, U.K. Government, 30 March 2023, see https://www.gov.uk/government/publications/powering-up-britain, accessed 12 September 2023.

606 - U.K. Parliament, "Financial Statement and Budget Report—Volume 729: debated on Wednesday 15 March 2023", 15 March 2023, see https://hansard.parliament.uk/commons/2023-03-15/debates/5603C6A5-C487-4D37-8658-F6403BF9E5A5/FinancialStatementAndBudgetReport, accessed 12 September 2023.

607 - Department for Energy Security and Net Zero, Great British Nuclear, and Nuclear Decommissioning Authority, "British nuclear revival to move towards energy independence", Press Release, U.K. Government, 18 July 2023, see https://www.gov.uk/government/news/british-nuclear-revival-to-move-towards-energy-independence, accessed 18 July 2023.

608 - Science, Innovation and Technology Committee, "Delivering nuclear power", U.K. Parliament, 31 July 2023, see https://publications.parliament.uk/pa/cm5803/cmselect/cmsctech/626/summary.html, accessed 15 October 2023.

Nuclear Newbuild

The U.K. has one power plant with two reactors under construction at Hinkley Point C, and one project with two units awaiting a final investment decision at Sizewell C. Both projects are based on the Franco-German European Pressurized Water Reactor (EPR) design. The development of two new reactors at Bradwell using the Chinese Hualong One design, has been halted at the site, and the project-dedicated website states "at this stage, we do not anticipate the work taking place in 2023".[609]

Hinkley Point C

The regulator concluded its five-year Generic Design Assessment (GDA) of the U.K. EPR in December 2012, and EDF Energy was given planning permission to build two reactors at Hinkley Point in April 2013. In October 2015, EDF and the U.K. Government[610] announced updates to the October 2013 provisional agreement of commercial terms of the deal for the £16 billion (US$$_{2013}$25 billion) overnight construction cost of Hinkley Point C (HPC).[611] The Chinese nuclear company China General Nuclear Power Group (CGN) is a wholly state-owned company and at the start of the project agreed to meet 33.5 percent of the investment. The estimated cost of construction has since risen at the following times:

- In 2017, it stood at £$_{2015}$19.6 billion (~US$$_{2015}$30 billion), up from £$_{2015}$18.1 billion (~US$$_{2015}$27.6 billion)—EDF said at the time that the £1.5 billion (~US$$_{2015}$2.3 billion) increase resulted mainly "from a better understanding of the design adapted to the requirements of the British regulators, the volume and sequencing of work on site and the gradual implementation of supplier contracts."[612]
- In September 2019, EDF announced a further increase in costs due to "challenging ground conditions", "revised action plan targets" and "extra costs needed to implement the completed functional design", with the new completion cost (still in 2015 values) now being estimated between £21.5 billion (US$32.8 billion) and £22.5 billion (US$34.3 billion). Furthermore, it was stated that the risk of delay had increased and that such a delay would increase costs by £0.7 billion (US$1.1 billion) over and above these estimates, so the upper end of the range was £23.2 billion (US$35.4 billion).[613] EDF stated that "management of the project remains mobilised to begin generating power from Unit 1 at the end of 2025", which does not appear to be a clear statement of confidence in the then-current schedule.[614] By then, construction had been launched less than a year earlier (in December 2018).

609 - Bradwell B Project Site, "Bradwell-on-Sea Residents Letter – 6 September 2022", CGN and EDF Energy, 6 September 2022, see https://bradwellb.co.uk/bradwell-on-sea-residents-letter-6-september-2022/, accessed 13 September 2023.

610 - Department of Energy & Climate Change, "Hinkley Point C to power six million UK homes", Press Release, U.K. Government, 21 October 2015, see https://www.gov.uk/government/news/hinkley-point-c-to-power-six-million-uk-homes, accessed 13 September 2023.

611 - Department of Energy and Climate Change and Prime Minister's Office, "Initial agreement reached on new nuclear power station at Hinkley", Press Release, U.K. Government, 21 October 2013, see https://www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley, accessed 13 September 2023.

612 - EDF, "Clarifications on Hinkley Point C project", Press Release, 3 July 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/clarifications-on-hinkley-point-c-project, accessed 13 September 2023.

613 - EDF, "Update on Hinkley Point C project", Press Release, 25 September 2019, see https://www.edfenergy.com/media-centre/news-releases/update-on-hinkley-point-c-project, accessed 13 September 2023.

614 - Ibidem.

- In its annual financial statement, published in March 2022, EDF confirmed that Unit 1 is expected to generate power in June 2026, compared to end-2025 as announced in 2016. The project completion costs were then estimated in the range of £$_{2015}$22–23 billion (US\$$_{2015}$33.6–35.1 billion), a rise of £0.5 billion (~US\$0.8 billion).[615]
- Less than three months later, in May 2022, EDF then announced that cost estimates had further risen by £$_{2015}$3 billion (US\$$_{2015}$4.6 billion), to between £$_{2015}$25–26 billion (US\$$_{2015}$38.2–39.7 billion) and that its start-up would be delayed by an additional year to June 2027, with the risk of further delay "assessed at 15 months".[616]
- In February 2023, EDF announced that the costs had risen again, now to £32 billion (US\$$_{2021}$44 billion), (note the previous £26 billion figures were in 2015 values, while £32 billion is in 2021 values, and so some of the rise in costs are inflationary).[617] EDF also announced that an additional delay of 15 months, remained possible.[618] EDF may have to cover all of the increase as it is thought an equity cap with CGN may have been reached.[619]

The critical point of the deal was a Contract for Difference (CfD), effectively a guaranteed real electricity price for 35 years, which, depending on the number of units ultimately built, i.e. whether construction at Sizewell C proceeds, would be £89.50–92.50/MWh (US\$$_{2023}$113–117/MWh), with annual increases until and from startup linked to the Retail Price Index.[620] In early 2020, EDF broke down the £92.50/MWh (US\$$_{2023}$117/MWh) strike price, saying that £19.5 (US\$$_{2023}$24.7) would cover operating and maintenance costs and only £11 (US\$$_{2023}$14) to overnight construction costs, excluding financing. The remaining £62 (US\$$_{2023}$78.5) would cover risk, with £26 (US\$$_{2023}$33) for financing costs for "typical regulated asset without construction risk" and £36 (US\$$_{2023}$45.6) to cover first-of-a-kind construction risk.[621]

Within the original 2016 CfD agreement, EDF is to receive a 35-year firm price per MWh, but if commercial operation starts after November 2029 the CfD is reduced in value until 2033. This is the "longstop date", after which the contract could be cancelled if the project is not completed.[622] On 29 November 2022, the longstop date was extended from 1 November 2033 to 1 November 2036.[623]

615 - EDF Energy, "Annual Report and Financial Statements", 29 April 2022, see https://www.edfenergy.com/sites/default/files/edf_energy_holdings_limited_fy21_signed_financial_statements_full.pdf, accessed 14 July 2023.

616 - EDF, "Hinkley Point C Update", Press Release, 19 May 2022, see https://www.edf.fr/sites/groupe/files/epresspack/3081/ccb6205433272bb0cbfac560cea3b537.pdf, accessed 13 September 2023.

617 - EDF, "2023: Q1 Sales and highlights—Appendices", February 2023, see https://www.edf.fr/sites/groupe/files/2023-04/2023-04-28-edf-book-q1-2023.pdf, accessed 13 September 2023.

618 - EDF, "2022 Annual Results", presented 17 February 2023, see https://www.edf.fr/sites/groupe/files/2023-04/annual-results-2022-presentation-2023-02-17-v3-2.pdf; and *NEI Magazine*, "EDF increases cost estimates for Hinkley Point C", *Nuclear Engineering International*, 21 February 2023, see https://www.neimagazine.com/news/newsedf-increases-cost-estimates-for-hinkley-point-c-10612738, accessed 13 September 2023.

619 - Nathalie Thomas and Sarah White, "EDF faces shouldering more of soaring bill for Hinkley Point", *Financial Times*, 17 February 2023, see https://www.ft.com/content/ae5fb399-08ce-4045-bb70-45a6531ac5f2, accessed 15 October 2023.

620 - EDF, "Agreement reached on commercial terms for the planned Hinkley Point C nuclear power station", Press Release, 21 October 2013.

621 - Phil Chaffee, "United Kingdom: Industry Pushes for Government Action", *Nuclear Intelligence Weekly*, 6 March 2020.

622 - NNB Generation Company (HPC) Limited and Low Carbon Contracts Company Ltd, "Contract for Difference for Hinkley Point C", September 2016, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1120647/1_-_Contract_for_Difference__redacted_.pdf, accessed 13 September 2023.

623 - Department for Energy Security & Net Zero and Department for Business, Energy & Industrial Strategy, "Hinkley Point C: contractual documents—Details", Updated 29 November 2022, see https://www.gov.uk/government/publications/hinkley-point-c-documents; and *NEI Magazine*, "EDF secures further funding Hinkley Point C", *Nuclear Engineering International*, 6 December 2022, see https://www.neimagazine.com/news/newsedf-secures-further-funding-hinkley-point-c-10414222, accessed 13 September 2023.

There was an expectation that construction would be primarily funded by debt (borrowing) backed by U.K. sovereign loan guarantees, expected to be up to about £17 billion (US$$_{2015}$25.9 billion), but the loan guarantees were never taken up.[624] In October 2015, it was revealed that EDF intended to sell non-core assets worth up to €10 billion (US$$_{2015}$11.1 billion) over five years to help finance HPC and other capital-intensive projects.[625]

The expected composition of the consortium owning the plant changed from October 2013 to October 2015 with the effective bankruptcy and dismantling of AREVA making their planned contribution of 10 percent impossible, the Chinese stake, through CGN, fell to 33.5 percent from 40 percent, and the other investors (up to 15 percent) had not materialized, leaving EDF with 66.5 percent rather than 45 percent it had hoped for in 2013. The rising construction cost and its increased share have impacted the amount EDF has to pay. Since 2013, the cost of EDF's expected project share has increased by about 150 percent[626] and significantly contributed to its large debt load.[627]

The administration of then Prime Minister Theresa May had finally approved and signed binding contracts for the HPC project in September 2016, with the government retaining a 'special share', that would give it a veto right over changes to ownership, including preventing EDF from selling down to less than 50 percent, if national security concerns arose.[628] The U.S. Government continued to have security concerns, and in October 2018 Assistant Secretary of State, Christopher Ashley Ford, warned the U.K. explicitly against partnering with CGN, saying that Washington had "evidence that the business was engaged in taking civilian technology and converting it to military uses."[629] Reportedly, U.S. officials have been "celebrating the UK's effort to push a Chinese company out of a sensitive nuclear power project" in the fall of 2021.[630] The comment refers to the Bradwell project, where CGN planned to build its design (see hereunder).

The HPC delays and cost overruns were part of the credit-rating agency Standard & Poor's (S&P) rationale to downgrade EDF's rating in February 2022[631], and its placement on credit-watch negative in May 2022[632]. In the same rating actions, S&P downgraded EDF's U.K.

624 - Phil Chaffee, "United Kingdom: Difficulties With Hinkley's IUK Support", *Nuclear Intelligence Weekly*, 4 December 2015.

625 - Michael Stothard, "EDF looks to sell €10bn of assets to boost balance sheet", *Financial Times*, 18 October 2015, see https://www.ft.com/content/fcd6a462-7578-11e5-a95a-27d368e1ddf7, accessed 25 June 2018.

626 - Steve Thomas and Alison Downes, "Financing the Hinkley Point C Project", Public Services International Research Unit, University of Greenwich, January 2020.

627 - EDF, "EDF Annual Results 2021", 18 February 2022, see https://www.edf.fr/sites/groupe/files/2022-02/5fef59d6cf90d62bc6a5390f70c3803d.pdf, accessed 13 September 2023.

628 - Rowena Mason and Simon Goodley, "Hinkley Point C nuclear power station gets government green light", *The Guardian*, 15 September 2016, see http://www.theguardian.com/uk-news/2016/sep/15/hinkley-point-c-nuclear-power-station-gets-go-ahead, accessed 19 July 2023.

629 - Jonathan Ford, "UK's reliance on China's nuclear tech poses test for policymakers", *Financial Times*, 14 February 2019, see https://www.ft.com/content/7734e3be-2f6f-11e9-8744-e7016697f225, accessed 19 July 2023.

630 - Anna Isaac, "US celebrates as UK looks to push China out of nuclear energy sites", *The Independent*, 29 September 2021, see https://www.independent.co.uk/news/business/news/us-china-nuclear-power-security-uk-b1929421.html, accessed 19 July 2023.

631 - S&P Global Ratings, "Research Update: Electricite de France Downgraded To 'BBB' From 'BBB+' On Strong Debt Increase In 2022-2023; Outlook Negative", Standard & Poor's, 22 February 2022, see https://www.edf.fr/sites/groupe/files/2022-02/sp-edf-ratings-direct-2022-02-21.pdf, accessed 19 July 2023.

632 - S&P Global Ratings, "Research Update: Electricite de France Placed On CreditWatch Negative On Further Nuclear Issues And Increase In Debt", Standard & Poor's, 24 May 2022, see https://www.edf.fr/sites/groupe/files/2022-05/sp-press-release-2022-05-24_0.pdf, accessed 19 July 2023.

subsidiary EDF Energy to BB, deep in speculative territory ("junk") and put it on credit-watch negative for potential further downgrade.

In June 2023, Moody's published a credit opinion on EDF Group reporting the downgrading of the Baseline Credit Assessment (BCA) from baa3 to ba1 due to slow progress in the recovery, high and volatile wholesale electricity prices and the group's significant debt burden. Around Hinkley Point they said

> The increasing cost estimates illustrate the execution risks that EDF and CGN face in constructing the power station. In addition, EDF's balance sheet will have to suffer the financial implications of a very long construction phase, given that the cost will have to be debt funded because the group has entered into a fixed-price contract-for-differences agreement with the UK government and has no ability to recover the higher costs from customers; and the investment will not generate any cash flow until the power plant is operational.[633]

A New Funding Model for Nuclear?

In March 2022, the U.K. Parliament finally adopted a Nuclear Energy (Financing) Act, which introduces a new funding model to facilitate the construction of new nuclear via a Regulated Asset Base (RAB),[634] after over two years of consultation, review and adoption process. RAB differs from the previously implemented Contracts for Difference (CfD) model on three key aspects. One is consumers paying finance costs, another is that the owners would be institutional investors such as pension funds or sovereign wealth funds, and the third is that the price is not fixed because, unlike CfD, the owners do not assume the risk of cost escalation and time overrun. If a project is taken forward under this model, the developer could charge consumers upfront for the construction, which would be broken down into different phases during the build process. Furthermore, consumers would pay the finance charges, so borrowing would be effectively interest-free to the owners in the construction phase.

It is noteworthy that in the Impact Assessment produced by the U.K. civil service to support the legislation, it was noted that on average construction costs were

> 20% higher than expected at the point of FID [Final Investment Decision] based on data from nth of a kind nuclear power plants built in Europe; and
>
> 100% higher than expected at the point of FID based on data from all nuclear power plants built after 1990.[635]

It is further noted that at the FID-stage for Hinkley Point C, it was estimated to have a construction cost (excluding financing) of £$_{2021}$6,400/kW (US$$_{2021}$8,803/kW), but the

633 - Moody's, "Electricite de France—Update following rating affirmation", 2023, see https://www.edf.fr/sites/groupe/files/2023-06/edf-credit-opinion-moodys-update-2023-06-06.pdf, accessed 19 July 2023.

634 - U.K. Parliament, "Nuclear Energy (Financing) Act 2022 Government Bill", House of Commons, first reading October 2022, see https://bills.parliament.uk/bills/3057; and U.K. Government, "Nuclear Energy (Financing) Act 2022—Chapter 5", enacted 31 March 2022, see https://www.legislation.gov.uk/ukpga/2022/15/enacted, accessed 13 September 2023.

635 - BEIS, "Regulated Asset Base Model for new nuclear—Impact Assessment", Department for Business, Energy & Industrial Strategy, U.K. Government, filed 26 October 2021, see https://publications.parliament.uk/pa/bills/cbill/58-02/0174/ImpactAssessment.pdf, accessed 19 July 2023.

government model is assuming construction costs of £$_{2021}$7,700–13,000/kW (US$$_{2021}$10,591–17,882/kW).[636]

Charging upfront reduces the overall construction costs as it avoids the need to include interest during the construction phase, thus cutting the amount of compounded debt to be serviced and paid off during the life of the asset, which could be critical for nuclear projects as financing represents a significant share of the overall project costs. EDF hopes that breaking the construction process into different phases is expected to increase certainty and, therefore, further reduce the cost of finance. EDF argues that the aim would be to reduce the weighted average cost of capital (WACC) from 9.2 percent on HPC to around 5.5–6 percent for follow-up projects.[637] However, in venture capital and private equity, funding rounds allow repricing of risk as more information becomes available on whether the venture is likely to work. This drive "up" rounds where the price per share is higher for subsequent investors and "down" rounds in the reverse. For nuclear, these would mostly be "down" rounds due to persistent delays in particular—which increase overall project costs.

When commenting on the RAB in 2019 an assessment by the National Infrastructure Commission concludes:

> it would be inappropriate to compare the price achieved under a CfD model, into which the developer has priced the risks of cost and time overruns, with a price achieved under a RAB model made on the basis that the project will be built on time and on budget.[638]

A key selling point for the government was the hope that funding would not have to come from the Treasury—and therefore remaining off the government's balance sheet. However, in October 2020, Energy Minister Kwasi Kwarteng reportedly told an event at the Conservative Party conference that the Treasury now believes that a nuclear RAB would be considered a U.K. Government balance sheet debt, given its support.[639]

Other U.K. New-Build Projects

In its spending review for 2021, the government announced that £1.7 billion (US$$_{2021}$2.3 billion) were being made available "to enable a final investment decision for a large-scale nuclear project in this Parliament" and that "the government remains in active negotiations with EDF over the Sizewell C project." In addition, the government was making available £385 million (US$$_{2021}$530 million) towards advanced nuclear Research & Development (R&D) and £120 million (US$$_{2021}$165 million) for a new Future Nuclear Enabling Fund to "address barriers to entry".[640]

636 - Ibidem.

637 - Jonathan Ford, "EDF seeks to charge customers upfront for UK nuclear plants", *Financial Times*, 22 November 2018, see https://www.ft.com/content/f9a96304-e980-11e8-885c-e64da4c0f981, accessed 19 July 2023.

638 - National Infrastructure Commission, "Estimating comparable costs of a nuclear regulated asset base versus a contract for difference financing model", October 2019, see https://nic.org.uk/app/uploads/NIC_RAB_Paper_October_2019-3rd-Layout-003.pdf, accessed 19 July 2023.

639 - Phil Chaffee, "United Kingdom: Policy Void Prompts Developer Scramble", *Nuclear Intelligence Weekly*, 30 October 2020.

640 - U.K. Government, "Autumn Budget and Spending Review 2021—A stronger economy for the British people", 27 October 2021, op. cit.

Sizewell C

Initially, it was proposed that EDF and CGN would develop a follow-on to HPC, the Sizewell C project. Chinese investment was to be limited to 20 percent, leaving EDF with 80 percent. EDF stated that it has planned to pre-finance the development of its share of the initial budget with up to a £458 million (US$$_{2022}$564 million). There was no agreement to invest beyond that stage.[641] On 24 June 2020, the Planning Inspectorate accepted the application for development consent and consequently the next stage of the planning process could begin.[642] However, in October 2020, EDF announced it intended to change the application, leading to further delay.[643] The government, in July 2022, gave its development consent to build Sizewell-C.[644]

EDF hoped to sequence the construction of Sizewell C with the completion of HPC, so that workers can move from one project to another. Nevertheless, this seems impossible given the earliest conceivable preliminary construction-works start-date of Sizewell C in 2024. EDF was optimistic that it could reduce construction costs, with its estimate in 2020 put at £18 billion (US$$_{2020}$23 billion).[645] However, they are also hoping that the financing costs of Sizewell-C can be reduced by shifting from the CfD mechanism to the RAB model. EDF has suggested that with a better financing model and no "first-of-a-kind costs", they could "peel away" the strike price by £36/MWh (US$$_{2023}$45.6/MWh),[646] as a result of EDF's "base case" for Sizewell C's cost being £20 billion (US$$_{2023}$25.3 billion), with 60 percent financed by loans.[647] In its planning documents, EDF confirmed construction cost estimates of "circa £20 billion" (US$$_{2020}$25.6 billion), despite previously suggesting that costs would be 20 percent lower than HPC, thus limited to £18 billion (US$$_{2020}$23 billion).[648]

In March 2021, EDF's financial report for 2020 said a Final Investment Decision (FID) was likely to be made in mid-2022, but used cautious language on the whole about the project, stating:

> EDF aims to ensure that risk sharing with the UK government in the as-yet un-validated regulatory and financing scheme will make it possible to find third-party investors during

641 - EDF, "Universal Registration Document 2021—Including the Annual Financial Report", filed 17 March 2022, pp.70–71, see https://www.edf.fr/sites/groupe/files/2022-03/edf-2021-universal-registration-document.pdf, accessed 12 July 2022.

642 - The Planning Inspectorate, "Application by NNB Nuclear Generation (SZC) Limited for an Order Granting Development Consent for The Sizewell C Project—Notification of decision to accept an application for Examination for an Order Granting Development Consent", Email to Richard Bull, EDF Energy, Ministry of Housing, Communities and Local Government, U.K. Government, 24 June 2020, see https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010012/EN010012-002268-A05%20Notification%20of%20decision%20to%20accept%20application_.pdf, accessed 19 July 2023.

643 - Richard Cornwell, "EDF formally submits proposed changes to Sizewell C plans", *East Anglian Daily Times*, 13 January 2021, see https://www.eadt.co.uk/news/sizewell-c-plans-changes-submitted-6900486, accessed 19 July 2023.

644 - Planning Inspectorate, "The Sizewell C Project development consent decision announced", Press Release, U.K. Government, 20 July 2022, see https://www.gov.uk/government/news/the-sizewell-c-project-development-consent-decision-announced, accessed 19 July 2023.

645 - *NEI Magazine*, "Plans for Sizewell C submitted to UK Planning Inspectorate", *Nuclear Engineering International*, 28 May 2020, see https://www.neimagazine.com/news/newsplans-for-sizewell-c-submitted-to-uk-planning-inspectorate-7943163, accessed 19 July 2023.

646 - Phil Chaffee, "United Kingdom: Industry Pushes for Government Action", *Nuclear Intelligence Weekly*, 6 March 2020.

647 - Roger Murray, "Hinkley Point Cost Overrun- Bad News for Sizewell C?", *Nuclear Intelligence Weekly*, 27 September 2019.

648 - SZC, "The Sizewell C Project—4.2 Funding Statement", Revision 1.0, EDF Energy and CGN, submitted to Infrastructure Planning Inspectorate, May 2020, see https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010012/EN010012-001678-SZC_Bk4_4.2_Funding_Statement.pdf; and Donato Paolo Mancini and Nathalie Thomas, "Cost of new Sizewell C nuclear plant put at £20bn", *Financial Times*, 26 June 2020, see https://www.ft.com/content/77c209f7-6d18-4609-ac3c-77d1b5b82b34, accessed 19 July 2023.

> the FID and avoid consolidating the project (including the economic debt calculation adopted by rating agencies). To date, it is not clear whether the group will reach this target.

It went on to say:

> EDF's ability to make an FID on Sizewell C and to participate in the financing of this project beyond the development phase could depend on the operational control of the Hinkley Point C project, on the existence of an appropriate regulatory and financing framework, and on the sufficient availability of investors and funders interested in the project. To date, none of these conditions are met.
>
> Failure to obtain the appropriate financing framework and appropriate regulatory approval could lead the Group not to make an investment decision or to make a decision in less than optimal conditions.[649]

In January 2022, the government reiterated its intention to see a FID on "at least one" large-scale nuclear project in this Parliament—which is set to run until December 2024. The government has also pledged £100 million (US$$_{2022}$123.3 million) for EDF to "help bring [the project] to maturity, attract investors and advance the next phase in negotiations". In return, the government will take rights over the land of Sizewell C, "should the project not ultimately be successful".[650]

In June 2022, the U.K. Government announced that the £100 million option that it had taken out in January would be converted into equity to take a 20 percent share in Sizewell C, should the project reach a final investment decision, with the apparent intention to ease the ousting of Chinese investors.[651] In the same week of July 2022 that the U.K. Government announced that Sizewell C had been granted development consent, it was announced by the French government that it would fully renationalize EDF (see France Focus).

Then in November 2022, the U.K. Government confirmed that it was stepping into the project investing £679 million (US$$_{2022}$837 million), of which the government refused to say how much has been used to buy out CGN, although the press suggested that it was £100 million (US$$_{2022}$123.3 million).[652] The departure of the Chinese investors from the project has meant that the U.K. Government and EDF will now each take a 50 percent equity stake in the Sizewell C project. With a further investment of £170 million (US$$_{2023}$215 million) announced on 24 July 2023, as of late July 2023, the government holds a 47 percent share

649 - EDF, "2020 Annual Results – Appendices", March 2021, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/publications/financial-results/2020-annual-results/pdf/annual-results-2020-appendices-20210304.pdf, accessed 19 July 2023.

650 - BEIS, "Government readies Sizewell C nuclear project for future investment", Press Release, Department for Business, Energy and Industrial Strategy, U.K. Government, 27 January 2022, see https://www.gov.uk/government/news/government-readies-sizewell-c-nuclear-project-for-future-investment, accessed 19 July 2023.

651 - Alex Lawson, "UK buys option to take 20% stake in Sizewell C nuclear power plant", *The Guardian*, 14 June 2022, see https://www.theguardian.com/environment/2022/jun/14/uk-buys-option-to-take-20-stake-in-sizewell-c-nuclear-power-plant, accessed 19 July 2023.

652 - EDF, "EDF welcomes the UK government's decision to invest in the development of Sizewell C", Press Release, 29 November 2022, see https://www.edf.fr/sites/groupe/files/epresspack/4235/PR_EDF-welcomes-the-UK-governments-decision-to-invest-in-the-development-of-Sizewell-C.pdf; and BEIS and Great British Nuclear "UK government takes major steps forward to secure Britain's energy independence", Press Release, U.K. Government, 29 November 2022; also Faye Brown, "China bought out of Sizewell C as UK confirms £700m stake in nuclear project", *Sky News*, 29 November 2022, see https://news.sky.com/story/sizewell-c-nuclear-power-plant-go-ahead-reconfirmed-with-700m-public-investment-shapps-announces-12757786, accessed 14 September 2023.

in the project.[653] However, it is both of their expectations that private investment will come into the project, reducing each of their shares to 20 percent. At minimum, this will require £12 billion (US$$_{2023}$15.2 billion) from further investors given the completion cost-estimate of £20 billion (US$$_{2023}$25.3 billion).[654] A more prudent investor might assume, given the experience from Hinkley Point C and current rates of inflation, to double that cost estimate.

Raising investment commitments is likely to be difficult, and two of Britain's most significant pension funds, the B.T. Pension Scheme and NatWest, explicitly ruled out to back the project.[655] Barclays Bank, appointed in June 2022 to run the investment process, will not start formal fundraising until 2023.[656] Other press reports suggest that talks have already begun with Sovereign Wealth Funds, such as the United Arab Emirates', to secure the necessary investment.[657]

Nevertheless, per latest announcements as of July 2023, EDF expects the FID to occur in 2024—provided certain conditions are met, including securement of financing.[658]

Bradwell

EDF is allowing CGN to use the Bradwell site it initially bought as a backup if either the Hinkley Point or Sizewell sites proved unsuccessful. CGN plans to build with its technology, the Hualong One (or HPR-1000) at this site, with EDF taking a 33.5 percent stake[659] up to the point of getting the Generic Design Assessment (GDA), going forward the plant will need a new consortium. In January 2017, the U.K. Government requested that the regulator begin the GDA of the HPR-1000 reactor,[660] and by 7 February 2022, the Office for Nuclear Regulation (ONR) issued the Design Acceptance Confirmation (DAC) and the Environment Agency released the Statement of Design Acceptability (SoDA).[661] In December 2020, the U.K.'s gas and electricity

653 - BEIS, "New steps to speed up construction work at Sizewell C", Press Release, U.K. Government, 24 July 2023, see https://www.gov.uk/government/news/new-steps-to-speed-up-construction-work-at-sizewell-c; and EDF, "2023 Half-Year Results—Appendices", 27 July 2023, see https://www.edf.fr/sites/groupe/files/2023-07/2023-07-27-half-year-results-book-presentation.pdf; both accessed 14 September 2023.

654 - Jim Pickard, "UK government to pay Chinese group £100mn to exit Sizewell C", *Financial Times*, 29 November 2022.

655 - Francesca Washtell and Daily Mail, "Two top UK pension funds snub Sizewell C nuclear plant plan", *This is Money*, 31 January 2023, see https://www.thisismoney.co.uk/money/markets/article-11697759/Two-UK-pension-funds-snub-Sizewell-C-nuclear-plant-plan.html, accessed 14 September 2023.

656 - Gill Plimmer and Jim Pickard, "Sizewell C nuclear plant funding drive likely to take until end of 2024", *Financial Times*, 3 March 2023.

657 - Francesca Washtell, "UAE wealth fund may invest in Sizewell C", *Financial Mail on Sunday*, as published on *This is Money*, 26 November 2022, see https://www.thisismoney.co.uk/money/markets/article-11472637/UAE-wealth-fund-invest-Sizewell-C.html, accessed 14 September 2023.

658 - EDF, "2023 Half Year Results", 27 July 2023, see https://www.edf.fr/sites/groupe/files/2023-07/2023-07-27-half-year-results-book-presentation.pdf; and Sam Tobin, "UK approval of Sizewell C nuclear plant lawful, court rules", *Reuters*, 22 June 2023, see https://www.reuters.com/business/energy/uk-approval-sizewell-c-nuclear-plant-lawful-court-rules-2023-06-22/, accessed 14 September 2023.

659 - EDF Energy, "Agreements in place for construction of Hinkley Point C nuclear power station", Press Release, 21 October 2015, see https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/news-views/agreements-in-place, accessed 19 July 2023.

660 - Office for Nuclear Regulation, Natural Resources Wales, and Environment Agency, "Assessing new nuclear reactor designs—Generic Design Assessment Periodic Report November 2016 – January 2017", March 2017, see http://www.onr.org.uk/new-reactors/reports/gda-quarterly-report-nov16-jan17.pdf, accessed 16 July 2023.

661 - ONR, "UK HPR1000—Design Acceptance – DAC/SoDA", Updated 13 April 2023, see https://www.onr.org.uk/new-reactors/uk-hpr1000/dac-soda.htm; and CGN and EDF, "UK HPR1000 ~ GDA Process", 7 February 2022, see https://www.ukhpr1000.co.uk/, accessed 19 July 2023.

markets regulator, Office of Gas and Electricity Markets (Ofgem), granted the Bradwell Power Generation Company Ltd an electricity generating license.[662]

In August 2019, the United States blacklisted CGN for allegedly diverting U.S. nuclear technology for "military uses" and added the state-owned Chinese firm and its three subsidiaries to its "entity list".[663] The move makes it virtually impossible for American companies to supply or cooperate with the company without specific permissions.[664] This and the increasing breakdown in the relationship between China, the U.S., and, to some extent, Europe will likely impact the development of Bradwell, as will the current economic climate. In particular, for the U.K., there is ongoing and growing concern over the situation in Hong Kong. Consequently, analysts suggested already in 2021 that, as nuclear power plants "are part of the UK's strategic national infrastructure, and China is no longer a friend to be trusted with such levers of power," it would be impossible to envisage the government approving the Bradwell project.[665]

Various media in the U.K. reported at the end of July 2021 that the government was investigating how to block CGN from operating future power plants in the U.K. which would effectively ban the company from engaging in either Sizewell C or Bradwell. The Chinese Government responded, "the British should earnestly provide an open, fair and non-discriminatory business environment for Chinese companies. China and the U.K. are important trade and investment partners for each other."[666]

In a highly critical report on the government's oversight of Chinese investment and engagement in the U.K., the Parliament's Intelligence and Security Committee concluded in July 2023 that:

> It is astonishing that the investment security process for Hinkley Point C did not therefore take Bradwell B into account. It is unacceptable for the government still to be considering Chinese involvement in the UK's Critical National Infrastructure (CNI) at a granular level, taking each case individually and without regard for the wider security risk. (...) Effective Ministerial oversight in this area is still lacking, more than eight years on from the Committee's Report on the national security implications of foreign involvement in the UK's CNI.[667]

662 - Ofgem, "Bradwell Power Generation Company Limited - Notice of grant of an electricity generation licence—Licence granted", Office of Gas and Electricity Markets, 16 December 2020, see https://www.ofgem.gov.uk/publications/bradwell-power-generation-company-limited-notice-grant-electricity-generation-licence, accessed 14 September 2023.

663 - Bureau au Industry and Security, "Addition of Certain Entities to the Entity List, Revision of Entries on the Entity List, and Removal of Entities From the Entity List", Department of Commerce, U.S. Government, Federal Register, Vol. 84, No.157, 14 August 2019, see https://www.govinfo.gov/content/pkg/FR-2019-08-14/pdf/2019-17409.pdf, accessed 14 September 2023.

664 - Todd Felix, "China nuclear firm blacklisted by US for 'unauthorised' use of tech", *NS Energy*, 15 August 2019, see https://www.nsenergybusiness.com/news/china-nuclear-us-tech/, accessed 19 July 2023.

665 - Nick Butler, "How growing conflict with China could impact UK nuclear power", *Prospect Magazine*, 10 April 2021, see https://www.prospectmagazine.co.uk/world/nuclear-investment-power-uk-china-government-energy, accessed 19 July 2023.

666 - *NEI Magazine*, "UK looks to ban CGN from participation in nuclear projects", *Nuclear Engineering International*, 27 July 2021, see https://www.neimagazine.com/news/newsuk-looks-to-ban-cgn-from-participation-in-nuclear-projects-8935996/, accessed 19 July 2023.

667 - Intelligence and Security Committee, "China", HC 1605, U.K. Parliament, 13 July 2023, see https://isc.independent.gov.uk/wp-content/uploads/2023/07/ISC-China.pdf, accessed 14 July 2023.

Other Sites and SMRs

Other sites have been proposed and developed to various degrees over the years. This includes Moorside in Cumbria being developed at some point by Toshiba-Westinghouse, Wylfa Newydd on Anglesey and Oldbury on Severn in South Gloucestershire, owned by Hitachi-GE. However, as of mid-2023, work had been suspended on all these sites.

Sort of Small Modular Reactors

In November 2020, to support the development of a potential next generation of reactors, the government proposed to provide up to £385 million (~US$500 million) in an Advanced Nuclear Fund, with up to £215 million (US$$_{2020}$276 million) going to Rolls-Royce's SMR program.[668] Rolls-Royce is in the final stages of completing its feasibility study. In 2021, it hoped its technology would complete the Generic Design Assessment (GDA) process with U.K. regulators around September 2024 to deliver the first power in about 2030[669], but as of 2023, the company aims to conclude Step 2 in July 2024, and the final phase in August 2026[670]. As noted in the chapter on SMRs (see section on United Kingdom), in November 2021, Rolls-Royce announced that it had received £210 million (US$$_{2021}$289 million) in government funding and £195 million (US$$_{2021}$268 million) in private funds and the following month an additional £85 million (US$$_{2021}$117 million) from the Qatar Investment Authority.[671]

The U.K.'s SMR program was closely linked to the delayed launch of Great British Nuclear. The lack of urgency around the launch of GB Nuclear, along with a Future Nuclear Enabling Fund—worth £120 million (US$153 million)—frustrated SMR vendors, and, according to the nuclear trade press, suggests, prior to its eventual launch, that, as of June 2023, "Whitehall [U.K. Government complex] shows no intention of speeding up its various nuclear programs – and indeed appears to be either behind on or backing out of a number of its commitments".[672]

The Rolls-Royce SMR is said to be able to be used for power, hydrogen production, and for the manufacturing of jet fuel, and its multipurpose would enable a more significant number of reactors to be installed. Rolls-Royce is confident about the price of the units and suggests that the nth-of-a-kind reactor (after five have been built) will be in the order of £1.8 billion (US$$_{2021}$2.4 billion) (Capex) for 440-MW units and at a cost of £40–60/MWh (US$$_{2021}$55–82.5/MWh) over 60 years.[673] In evidence submitted in 2017, Rolls-Royce told the House of Lords, that 7 GW would "be of sufficient scale to provide a commercial return on investment from a

668 - BEIS, "Advanced Nuclear Technologies", Policy Paper, Department for Business, Energy and Industrial Strategy, U.K. Government, Updated 15 August 2023, see https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies, accessed 14 September 2023.

669 - *WNN*, "Rolls-Royce on track for 2030 delivery of UK SMR ", *World Nuclear News*, 11 February 2021, see https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR, accessed 19 July 2023.

670 - U.K. Government, "Decision—GDA Step 1 statement: summary on the Rolls-Royce SMR", 3 April 2023, see https://www.gov.uk/government/publications/gda-step-1-of-the-rolls-royce-smr-statement-of-findings/gda-step-1-statement-summary-on-the-rolls-royce-smr, accessed 14 September 2023.

671 - Rolls-Royce, "Funding secured to enable small modular reactor delivery to meet net zero", Press Release, 8 November 2021, see https://www.rolls-royce-smr.com/press/funding-secured-to-enable-small-modular-reactor-delivery-to-meet-net-zero; and Rolls-Royce, "Rolls-Royce and QIA announce nuclear investment", Press Release, 20 December 2021, see https://www.rolls-royce-smr.com/press/rolls-royce-and-qia-announce-nuclear-investment; both accessed 14 September 2023.

672 - Grace Symes, "United Kingdom: Vendors Eager for 'Clarity' on SMR Competition", *Energy Intelligence*, 16 June 2023.

673 - *WNN*, "Rolls-Royce on track for 2030 delivery of UK SMR", *World Nuclear News*, 11 February 2021, see https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR, accessed 14 September 2023.

UK-developed SMR, but it would not be sufficient to create a long-term, sustainable business for UK plc." The House of Lords concluded: "Therefore, any SMR manufacturer would have to look to export markets to make a return on their investment."[674]

The capital cost estimate is a heroic assumption equating to £4,000/kW (US$4,858/kW) compared to what EDF estimates for the cost of Sizewell C of £5,600/kW (US$6,802/kW) and the current cost of Hinkley Point C of £8,100/kW (US$9,838/kW). It is fair to say that if there were any confidence that the SMRs would be delivered at the quoted cost within a foreseeable timeframe, construction projects of Sizewell C and any similar-sized reactors would be abandoned.

Technically speaking, the Rolls-Royce design is not an SMR. These are in a 30–300 MW range according to a definition used by the IAEA and most national and international organizations (see chapter on SMRs).

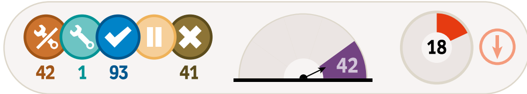
Conclusion

While nuclear power has become one of the cornerstones of the U.K. Government's future energy security policy, it seems unlikely—despite the various proposed measures—that there will be an acceleration of the development of nuclear power over the coming decade. Furthermore, given the government's commitment to have a zero-carbon power sector by 2035, before significant new nuclear capacity can come online, the likelihood of additional nuclear, beyond Hinkley Point C and possibly Sizewell C in the late 2030s and beyond, seems remote.

Elections are to be held in the U.K. before January 2025, and there is possibly to be a change in administration, as the Labour Party has been ahead in the opinion polls for over a year. While on the one hand, this is unlikely to change the fortunes of nuclear power, as Labour also sees nuclear power as a 'critical part' of the U.K.'s power mix, on the other, they are likely to be significantly more supportive of renewable energy and, in particular onshore renewable energy, that is currently blocked, mainly in England. It could significantly and rapidly unlock, along with sizeable offshore wind, vast amounts of renewable electricity production. The Labour Party has a target of decarbonizing the power sector by 2030 which if met would demonstrate that very little, if any, nuclear power is needed to decarbonize the power sector.

674 - Science and Technology Committee, "Nuclear research and technology: Breaking the cycle of indecision", House of Lords, May 2017, see https://publications.parliament.uk/pa/ld201617/ldselect/ldsctech/160/160.pdf, accessed 19 July 2023.

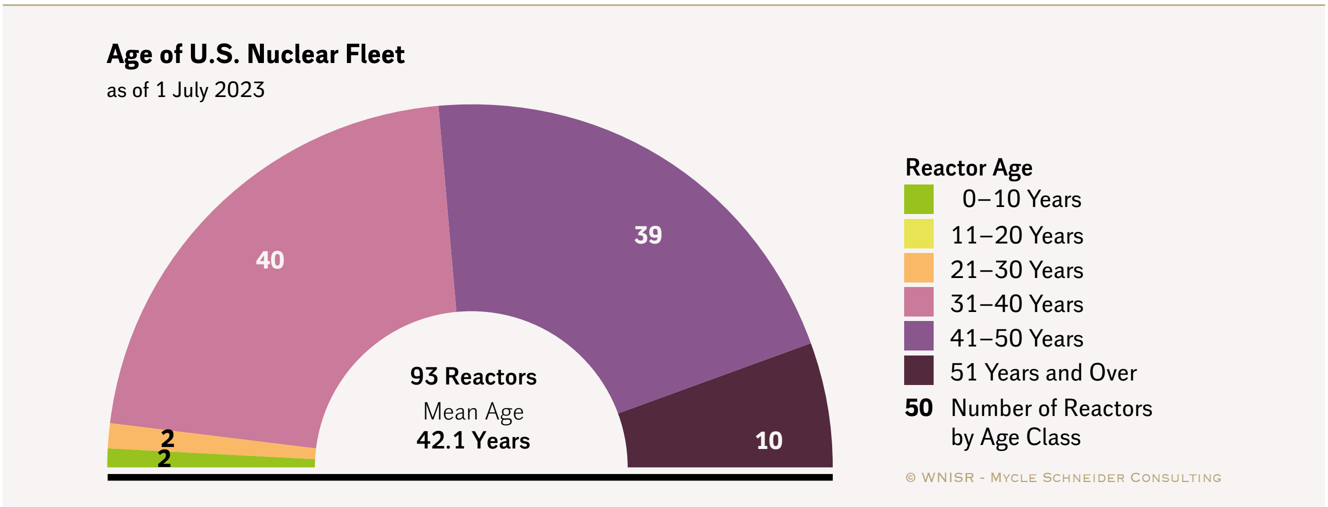
UNITED STATES FOCUS



Overview

With 93 commercial reactors operational as of 1 July 2023, the United States has by far the largest nuclear fleet in the world. Nuclear energy generation in 2022 remained constant (+0.1), according to IAEA-PRIS, it declined by 0.9 percent to 771.5 TWh, according to preliminary national data, the least since 2012.[675] The sector's share of utility-scale electricity generation fell from 19.6 percent to 18.2 percent, the lowest in 25 years.[676] Counting non-commercial rooftop solar PV generation (which increased 19 percent year-over-year), nuclear's share of total electricity was lower, at 17.9 percent, while renewable energy sources widened their margin over nuclear, with 22.6 percent of total electricity generation. The U.S. fleet continues to age, with a mid-2023 average of 42.1 years, making it amongst the oldest in the world: 49 units have operated for 41 years or more (of which 10 for more than 51 years) and all but four for 31 years or more (see Figure 50).

Figure 50 • Age Distribution of U.S. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2023

After 10 years of construction, the first of two new Westinghouse AP-1000 reactors at Plant Vogtle—Unit 3—was connected to the grid on 1 April 2023.[677] The reactor reached full power

675 - U.S. EIA, "U.S. Nuclear Generation and Generation Capacity", United States Energy Information Administration, 29 June 2023, see https://www.eia.gov/nuclear/generation/, accessed 21 July 2023.

676 - According to IAEA-PRIS. U.S.EIA and NEI data are slightly different; see U.S.EIA, "Electricity data browser—Net generation for all sectors", U.S. Energy Information Administration, Undated, see https://www.eia.gov/electricity/data/browser/#/topic/0?agg=2,0,1&fuel=vtvv&geo=g&sec=g&linechart=ELEC.GEN.ALL-US-99.A~ELEC.GEN.COW-US-99.A~ELEC.GEN.NG-US-99.A~ELEC.GEN.NUC-US-99.A~ELEC.GEN.HYC-US-99.A~ELEC.GEN.WND-US-99.A~ELEC.GEN.TSN-US-99.A&columnchart=ELEC.GEN.ALL-US-99.A~ELEC.GEN.COW-US-99.A~ELEC.GEN.NG-US-99.A~ELEC.GEN.NUC-US-99.A~ELEC.GEN.HYC-US-99.A~ELEC.GEN.WND-US-99.A&map=ELEC.GEN.ALL-US-99.A&freq=A&ctype=linechart&ltype=pin&rtype=s&maptype=0&rse=0&pin=, accessed 21 July 2023; and NEI, "U.S. Nuclear Generating Statistics: From 1971-2021", Nuclear Energy Institute, August 2022, see https://www.nei.org/resources/statistics/us-nuclear-generating-statistics, accessed 21 September 2023.

677 - Georgia Power, "Vogtle 3 & 4 nuclear units take significant steps toward operations", Press Release, 1 April 2023, see https://www.georgiapower.com/company/news-center/press-releases.html, accessed 10 August 2023.

on 29 May 2023,[678] but it encountered multiple operational problems[679] that kept the reactor offline for most of May, June, and July (see The Vogtle Debacle below). Southern Company (parent company of controlling owner, Georgia Power, and Plant Vogtle operator, Southern Nuclear) was able to return the reactor to full power on 29 July 2023,[680] and it was formally placed into commercial operation on 31 July.[681]

Costs have continued to increase as a result of creeping schedule delays since mid-2022. Southern Company reported US$461 million in additional costs for the second half of 2022.[682] All-in costs of the project exceed US$35 billion as of August 2023,[683] counting US$3.7 billion in rebates then-Westinghouse-owner Toshiba paid to the co-owners in 2017.[684]

Vogtle-4 completed hot functional testing in May 2023,[685] and Southern Company submitted the final technical inspections (called Inspections, Tests, Analyses, and Acceptance Criteria, or ITAACs) to the U.S. Nuclear Regulatory Commission (NRC) in July 2023.[686] The NRC notified Southern on 28 July that it has accepted the ITAACs, thereby clearing Vogtle-4 to begin loading fuel and startup tests.[687] Southern Company still projects that the reactor will be online in late 2023 or early 2024.[688]

The availability of federal subsidies has introduced uncertainty into planned retirements of reactors and, as appears likely, the overall rate of retirements. A proposal to extend operation of the Diablo Canyon-1 and -2 reactors for five years has advanced since reported in WNISR2022:

- The NRC granted owner Pacific Gas and Electric Company (PG&E) an exemption to its timely filing requirement in March 2023, which will allow the reactors to continue

678 - Georgia Power, "Vogtle Unit 3 reaches 100% power for the first time", Press Release, 29 May 2023, see https://www.georgiapower.com/company/news-center/2023-articles/vogtle-unit-3-reaches-100-percent-energy-output.html, accessed 13 June 2023.

679 - Jeff Amy, "Georgia Power says Vogtle nuclear reactor delayed another month by turbine problem", *The Associated Press*, 16 June 2023, see https://apnews.com/article/georgia-power-vogtle-nuclear-power-plant-southern-a0ede9dd77842cf5c9b0c2a0a71de970, accessed 4 August 2023.

680 - U.S. NRC, "Power Reactor Status Report for July 29, 2023—Unevaluated Information Provided by the Facility", United States Nuclear Regulatory Commission, Updated 31 July 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2023/20230729ps.html, accessed 4 August 2023.

681 - Georgia Power, "Vogtle Unit 3 goes into operation", Press Release, 31 July 2023, see https://www.georgiapower.com/company/news-center/press-releases.html, accessed 10 August 2023.

682 - Georgia Power, "Twenty-eighth Semi-annual Vogtle Construction Monitoring Report", Docket No. 29849, submitted to Georgia Public Service Commission, 16 February 2023, see https://services.psc.ga.gov/api/v1/External/Public/Get/Document/DownloadFile/193355/74970; and Stanley Dunlap, "Cost controversies still inflame critics of Plant Vogtle expansion as kilowatts go online", *Georgia Recorder*, 5 June 2023, see https://georgiarecorder.com/2023/06/05/cost-controversies-still-inflame-critics-of-plant-vogtle-expansion-as-kilowatts-go-online/; both accessed 19 August 2023.

683 - Drew Kann, "Is Vogtle the dawn of a new nuclear age or a costly warning sign?", *The Atlanta Journal-Constitution*, 4 August 2023, see https://www.ajc.com/news/is-vogtle-the-dawn-of-a-new-nuclear-age-or-a-costly-warning-sign/BNVND4BWORCPPNMB5LE5ZVMM4I/, accessed 10 August 2023.

684 - Jeff Amy, "Georgia nuclear rebirth arrives 7 years late, $17B over cost", *The Associated Press*, 25 May 2023, see https://apnews.com/article/georgia-nuclear-power-plant-vogtle-rates-costs-75c7a413cda3935dd551be9115e88a64, accessed 21 July 2023.

685 - Georgia Power, "Hot Functional Testing completed for Vogtle Unit 4", Press Release, 1 May 2023, see https://www.georgiapower.com/company/news-center/2023-articles/hot-functional-testing-completed-for-vogtle-unit-4.html, accessed 10 August 2023.

686 - Georgia Power, "All ITAACs have been submitted for Vogtle Unit 4", Press Release, as published on *PR Newswire*, 21 July 2023, see https://www.prnewswire.com/news-releases/all-itaacs-have-been-submitted-for-vogtle-unit-4-301882747.html, accessed 21 July 2023.

687 - Georgia Power, "Vogtle Unit 4 has received the 103(g) finding from the Nuclear Regulatory Commission", Press Release, 28 July 2023, see https://www.prnewswire.com/news-releases/vogtle-unit-4-has-received-the-103g-finding-from-the-nuclear-regulatory-commission-301888252.html, accessed 29 July 2023.

688 - Southern Company, "Vogtle Unit 3 goes into operation", Press Release, 31 July 2023, see https://www.southerncompany.com/newsroom/clean-energy/vogtle-unit-3-goes-into-operation.html, 11 August 2023.

operating after their current licenses expire—in November 2024 and August 2025, respectively—while the license extension application is under review.[689] PG&E must submit the application by the end of 2023.

- The U.S. Department of Energy (DOE) certified Diablo Canyon eligible to receive US$1.1 billion in Civil Nuclear Credits (CNC) in November 2022.[690]
- The latter approval also cleared the way for a US$1.4 billion loan to PG&E from the State of California to extend the reactors' operations to 2029 and 2030, respectively.[691]
- Until 2030, Diablo Canyon will be exempted from the state's regulation prohibiting coastal power plants from using once-through cooling systems.

Diablo Canyon is the first, and so far, only nuclear power plant approved under the new CNC program authorized in 2021 (see Securing Subsidies to Prevent Closures).

As reported in previous WNISR editions, a 2016 agreement between PG&E, four environmental organizations, and two labor unions that represent Diablo Canyon workers provided for the plant to close when the reactors' original 40-year operating licenses expire. Subject to the agreement, PG&E withdrew a license renewal application and environmental groups dropped various legal challenges in 2018. One of the parties to the agreement, Friends of the Earth, in April 2023, has filed suit against PG&E for violating the terms of the agreement.[692] On 30 June 2023, Friends of the Earth and two other organizations, Environmental Working Group and San Luis Obispo Mothers for Peace, filed an appeal in U.S. Circuit Court of the NRC's timely filing decision for the Diablo Canyon license renewal application.[693]

One reactor which was closed in 2022,[694] Palisades, in the state of Michigan, is the subject of an effort to recommission and resume its operation. The owner of Palisades (Holtec) applied for the CNC, but in November 2022, DOE determined that the reactor was not eligible,[695] having been defueled and officially retired in June 2022. Under NRC regulations, upon certifying final removal of fuel from the reactor, the operating license converts to a "possession-only license"

689 - U.S. NRC, "NRC Grants 'Timely Renewal' Exemption to Allow Continued Operation of Diablo Canyon Nuclear Power Plant", Press Release No. 23-015, United States Nuclear Regulatory Commission, 2 March 2023, see https://www.nrc.gov/cdn/doc-collection-news/2023/23-015.pdf, accessed 11 August 2023.

690 - Grid Deployment Office, "Civil Nuclear Credit Award Cycle 2", U.S. Department of Energy, Undated, see https://www.energy.gov/gdo/civil-nuclear-credit-award-cycle-1, accessed 11 August 2023.

691 - Catherine Clifford, "California lawmakers vote to extend Diablo Canyon nuclear plant operations as state battles energy emergency", *CNBC*, 1 September 2022, see https://www.cnbc.com/2022/09/01/california-lawmakers-vote-to-keep-diablo-canyon-nuclear-plant-open.html, accessed 1 September 2022.

692 - Michael R. Blood, "Lawsuit seeks to uphold closing California's last nuke plant", *The Associated Press*, 12 April 2023, *see* https://apnews.com/article/diablo-canyon-nuclear-extension-california-reactors-pge-cd398f8251311053b08aa8fbfcfa8ef4, accessed 3 August 2023.

693 - Mackenzie Shuman, "Groups appeal NRC's decision to keep Diablo Canyon open: 'Simply unacceptable'", *San Luis Obispo Tribune*, 12 July 2023, see https://www.sanluisobispo.com/news/local/environment/article277070823.html; and San Luis Obispo Mothers for Peace, Friends of the Earth and Environmental Working Group, "Case No. 23-852—On Appeal from the Nuclear Regulatory Commission's Final Agency Decision—Petitioners' Opening Brief", Before the U.S. Court of Appeals for the Ninth Circuit, 30 June 2023, see https://mothersforpeace.org/wp-content/uploads/2023/07/2023.06.30-Petitioners-Opening-Brief.pdf; both accessed 11 August 2023.

694 - Carolyn Muyskens, "The Palisades nuclear plant is offline. What happens next and is it closed for good?", *Holland Sentinel*, 27 May 2022, see https://www.hollandsentinel.com/story/news/local/2022/05/27/palisades-nuclear-power-plant-prepares-decommissioning/9923747002/, accessed 29 August 2022.

695 - Hannah Mackay, "Palisades nuclear power plant denied federal funds to reopen", *The Detroit News*, 22 November 2022, see https://www.detroitnews.com/story/news/local/michigan/2022/11/20/palisades-nuclear-power-plant-denied-federal-funds-to-reopen/69663890007/, accessed 21 July 2023.

for purposes of radiological decommissioning. In early July 2023, the State of Michigan approved US$150 million to help Holtec finance a restart, and in addition, Holtec has applied to the DOE for a loan guarantee of close to US$1 billion.[696]

Federal Subsidies and Financing for Nuclear Power

As reported in WNISR2022, the U.S. Congress enacted two major pieces of infrastructure and energy finance legislation in 2021 and 2022: the Infrastructure Investment and Jobs Act (IIJA),[697] with US$1.2 trillion in proposed spending[698]; and the Inflation Reduction Act (IRA),[699] with US$437 billion.[700] Each law includes significant new spending to promote nuclear energy—existing reactors, new reactors, and enrichment infrastructure.

As mentioned above, the IIJA authorized US$6 billion for the Civil Nuclear Credits program to support uneconomic reactors at imminent risk of closure,[701] as well as US$3.2 billion to support DOE's Advanced Reactor Demonstration Program, US$2.5 billion of which is allocated to cost-sharing grants for two commercial demonstration projects: TerraPower's Natrium project in Wyoming, a sodium-cooled fast reactor design based on GE's PRISM reactor; and a 4-unit SMR plant by X-energy using its Xe-100 high-temperature, gas-cooled reactor design. The IIJA also included US$8 billion in cost-sharing grants for at least four regional hydrogen hub demonstration projects, at least one of which must include use of a nuclear power plant to produce hydrogen.[702]

"This is certainly the largest direct federal investment in commercial nuclear energy in decades."

The IRA included a series of measures that provide subsidies and financing for existing and new reactors (see Securing Subsidies to Prevent Closures hereunder). The total amount of spending for nuclear energy under these measures is not yet determined but is certainly the largest direct federal investment in commercial nuclear energy in decades. Congress's Joint Committee on Taxation's (JCT) estimate of the bill's budget impacts projected the Production Tax Credits (PTC) for existing reactors to cost US$30 billion over the first eight years of

696 - Sheri McWhirter, "Palisades nuclear plant gets $150 million in Michigan budget", *Mlive*, 3 July 2023, see https://www.mlive.com/public-interest/2023/07/palisades-nuclear-plant-gets-150-million-in-michigan-budget.html; and John Adkins, "Holtec Seeks Federal Help For US's First Restart Of Shut-Down Nuclear Plant", *NucNet*, 5 June 2023, see https://www.nucnet.org/news/holtec-seeks-federal-help-for-us-s-first-restart-of-shut-down-nuclear-plant-6-1-2023; both accessed 11 August 2023.

697 - House Transportation and Infrastructure Committee, "H.R. 3684—Infrastructure Investment and Jobs Act", Public Law No. 117-58 enacted 15 November 2021, U.S. Congress, see https://www.congress.gov/bill/117th-congress/house-bill/3684, accessed 3 September 2022.

698 - Heather Long, "What's in the $1.2 trillion infrastructure law", *The Washington Post*, 16 November 2021, see https://www.washingtonpost.com/business/2021/08/10/senate-infrastructure-bill-what-is-in-it/, accessed 3 September 2022.

699 - House Budget Committee, "H.R. 5376—Inflation Reduction Act of 2022", Public Law No. 117-169 enacted 16 August 2022, U.S. Congress, see https://www.congress.gov/bill/117th-congress/house-bill/5376, accessed 3 September 2022.

700 - Chelsey Cox, "Biden signs Inflation Reduction Act into law, setting 15% minimum corporate tax rate", *CNBC*, 17 August 2022, see https://www.cnbc.com/2022/08/16/watch-live-biden-to-sign-inflation-reduction-act-into-law-setting-15percent-minimum-corporate-tax-rate.html, accessed 3 September 2022.

701 - Grid Deployment Office, "Civil Nuclear Credit Program", U.S. Department of Energy, Undated, see https://www.energy.gov/gdo/civil-nuclear-credit-program, accessed 11 August 2023.

702 - The White House, "Building A Better America—A Guidebook to the Bipartisan Infrastructure Law for State, Local, Tribal, and Territorial Governments, and Other Partners", U.S. Government, May 2022, see https://www.whitehouse.gov/wp-content/uploads/2022/05/BUILDING-A-BETTER-AMERICA-V2.pdf, accessed 14 August 2023.

the program (from 2024 through 2031).[703] Federal agencies have begun implementing these programs, but not all the details have been finalized, so reliable estimates of the costs of the nuclear incentives are not available. The Energy Policy Act of 2005 (EPACT 2005) was the previous law authorizing large amounts of federal funding for commercial nuclear energy,[704] allowing DOE to provide up to US$18 billion in loan guarantees for new reactors,[705] up to US$6 billion in production tax credits, US$2 billion in grants to compensate for delays in reactor licensing, and US$1.25 billion for a Next Generation Nuclear Plant Project. The Vogtle-3 and -4 project was granted US$12 billion in loan guarantees;[706] also, because the new Vogtle reactors would be the only facilities eligible to claim EPACT 2005's nuclear PTC, less than half of the US$6 billion authorized for the credits will ultimately be expended. The JCT provided no breakdown by energy source/technology of the other tax credits and loan guarantees for which commercial reactors are eligible, but the Nuclear PTC alone will exceed the value of all EPACT 2005 incentives for commercial reactors, based on the JCT's cost estimate.

The IRA's enormous expansion of the DOE's loan guarantee programs also increases the pace at which DOE must push money out the door. The authorizations for an additional US$40 billion under the existing program and the US$250 billion for existing energy facilities under the newly created Energy Infrastructure Reinvestment Financing program each expire on 30 September 2026, providing only four years for DOE to issue up to US$290 billion in loans to energy projects. Under the EPACT 2005 loan program, the agency's implementation of loan guarantees has long been criticized for lack of transparency and questionable management.

In 2013, analysts issued a report on the DOE's management of the initial US$8.33 billion loan guarantee to the Vogtle-3 and -4 construction project. Synapse Energy Economics and Earth Track reviewed hundreds of DOE documents obtained through Freedom of Information Act requests and found several areas of concern, including:

- Credit subsidy payments "far too low to offer adequate protection to taxpayers in the event of a default";
- Extensive outsourcing of "important risk oversight functions," suggesting "government's ability to properly structure and monitor the deal may be insufficient";

703 - Joint Committee on Taxation, "Estimated Budget Effects Of The Revenue Provisions Of Title I – Committee On Finance, Of An Amendment In The Nature Of A Substitute To H.R. 5376, 'An Act To Provide For Reconciliation Pursuant To Title II Of S. Con. Res. 14,' As Passed By The Senate On August 7, 2022, And Scheduled For Consideration By The House Of Representatives On August 12, 2022", JCX-18-22, U.S. Congress, 9 August 2022, see https://www.jct.gov/publications/2022/jcx-18-22/, accessed 4 August 2023.

704 - 109th U.S. Congress, "Energy Policy Act of 2005", Public Law 109–58 enacted 8 August 2005, U.S. Government, see https://www.congress.gov/109/plaws/publ58/PLAW-109publ58.pdf, accessed 7 September 2022.

705 - EPACT 2005 did not appropriate funds for the loan guarantee program, but subsequent appropriation bills in 2007 and 2009 authorized DOE to provide up to US$18.5 billion in loan guarantees for new reactors and up to US$4 billion for fuel cycle facilities. See U.S. DOE, "History: Loan Programs Office", U.S. Department of Energy, U.S. Government, see https://www.energy.gov/lpo/innovative-clean-energy-nuclear-loan-guarantees; and U.S. Congress, "Omnibus Appropriations Act, 2009", Public Law No. 111-8, Division C, Title III, 11 March 2009, United States Congress, see http://www.gpo.gov/fdsys/pkg/PLAW-111publ8/html/PLAW-111publ8.htm; both accessed 11 August 2023.

706 - Loan Programs Office, "Vogtle", U.S. Department of Energy, Undated, see https://www.energy.gov/lpo/vogtle, accessed 11 August 2023.

- Politicization of the loan's administration, through apparent involvement of the White House, the Secretary of Energy, and top Treasury Department officials in the Vogtle construction project.[707]

In 2017, four years after the DOE approved the initial Vogtle project loan, the project's cost ballooned to US$25 billion, and Westinghouse declared bankruptcy and canceled its management of the project. Despite the evident risk of the project, the cancellation of the only other Westinghouse AP-1000 construction project (Summer-2 and -3), the suspension or cancellation of all other proposed AP-1000 projects in the U.S., and Westinghouse's announcement that it would no longer market the design in the U.S., DOE issued US$3.67 billion in additional loan guarantees, again with no credit subsidy cost charged to the borrowers.

In June 2022, the Office of the Inspector General (OIG), an independent oversight office in each federal agency, issued a report in which it cited "four major risk areas that warrant immediate attention and consideration from Department leadership to prevent similar problems from recurring", similar to those identified in the 2013 Vogtle loan guarantee report:

- Insufficient Federal Staffing;
- Inadequate Policies, Procedures, and Internal Controls;
- Lack of Accountability and Transparency;
- Potential Conflicts of Interest and Undue Influence.[708]

While the IRA included a total of US$8.6 billion in appropriations to DOE for administration of the energy project loan guarantee programs, which may assist in increasing the agency's staffing, the legislation did not include provisions to address the other concerns about the loan guarantee program's management.

Policies, Planning, and Proposals for New Reactors

As one insider put it to *Reuters* news agency in 2021, "There's a deepening understanding within the [Biden] administration that it needs nuclear to meet its zero-emission goals."[709] With no prospects of major nuclear plant construction in the coming years,[710] the legislative efforts have focused on providing subsidies to prevent further reactor closures. It is unclear to what extent the funding allocated in the IIJA and the IRA will successfully prolong the operation of otherwise uneconomical reactors through direct subsidies and lowering the industry's risk exposure to financing large maintenance projects (e.g. steam generator replacements). The

707 - Doug Koplow and Max Chang, "Review of Documents Pertaining to Department of Energy Conditional Loan Guarantees for Vogtle 3 & 4", Earth Track and Synapse Energy Economics, January 2013, see https://www.earthtrack.net/document/review-documents-pertaining-department-energy-conditional-loan-guarantees-vogtle-3-4, accessed 22 September 2023.

708 - Office of Inspector General, "Special Report: DOE-OIG-22-34—Prospective Considerations for the Loan Authority Supported Under the Loan Programs Office to Improve Internal Controls and Prevent Fraud, Waste, and Abuse", U.S. Department of Energy, 10 June 2022, see https://www.energy.gov/ig/articles/special-report-doe-oig-22-34, accessed 22 September 2023.

709 - Timothy Gardner and Jarrett Renshaw, "U.S. eyes nuclear reactor tax credit to meet climate goals -sources", *Reuters*, 5 May 2021, see https://www.reuters.com/business/sustainable-business/white-house-eyes-subsidies-nuclear-plants-help-meet-climate-targets-sources-2021-05-05/, accessed 22 July 2021.

710 - Mark Cooper, "Building a Least-Cost, Low-Carbon Electricity System With Efficiency, Wind, Solar, & Intelligent Grid Management: Why Nuclear Subsidies Are an Unnecessary Threat to the Transformation", Institute for Energy and the Environment, Vermont Law School, July 2021, see https://www.vermontlaw.edu/sites/default/files/2021-07/Building_a_21st_Century_Electricity_System.pdf, accessed 22 July 2022.

much larger federal investments in existing reactors than in new construction suggest the U.S. industry is focused on treading water rather than on breaking ground in the next decade.

However, the significant amount of financial support for nuclear in the IRA and IIJA has generated widespread interest in new reactor designs. Since the IIJA was enacted, several states have enacted legislation and initiated programs to promote nuclear energy, and several utilities have initiated feasibility studies or included deployment of new reactors in their official long-range system plans (referred to in many states as Integrated Resource Plans or IRPs).

As of 2023, the schedules for three commercial reactor demonstration projects have slipped to 2030. The DOE awards to the TerraPower and X-energy plants are funded by the IIJA. They were selected in 2020 as the flagship projects of DOE's Advanced Reactor Demonstration Program (ARDP) with a goal of bringing reactors online in 5–7 years.[711] The ARDP is also supporting development of eight other reactor designs, with goals for deployment of demonstration reactors, at the soonest, in the early- to mid-2030s.

Eight states enacted legislation promoting new nuclear generation in 2022 and 2023. The measures enacted include repealing existing bans on nuclear plant construction, funding feasibility studies and establishing nuclear development boards, and authorizing nuclear plant financing:

- **Colorado:** The state legislature enacted a bill (HB23-1247) in 2023 with modest funding for a feasibility study of deploying "firm dispatchable energy resources" (including "advanced nuclear").[712]
- **Connecticut:** The legislature created an exception to the state's longstanding prohibition on construction of new reactors.[713] The legislation enacted in 2022 (HB 5202) permits construction of new reactors at the Millstone Nuclear Power Plant in Waterford, where there are two operational reactors and one retired reactor.
- **Idaho:** Legislators amended the Idaho Energy Resources Authority Act in 2023 to replace "renewable energy" with "clean energy", with a definition of the latter that adds nuclear to a list of energy facilities that the Energy Resources Authority may finance.[714]
- **Indiana:** In 2022, the legislature enacted a law (SB271) that authorizes the Indiana Utility Regulatory Commission to provide construction work in progress (CWIP) financing to utilities for construction of SMRs.[715] In 2023, legislators amended the definition of SMR

711 - Office of Nuclear Energy, "Advanced Reactor Demonstration Program", U.S. Department of Energy, Undated, see https://www.energy.gov/ne/advanced-reactor-demonstration-program, accessed 5 August 2023.

712 - Colorado General Assembly, "Assess Advanced Energy Solutions In Rural Colorado", HB23-1247, First Regular Session, introduced 14 March 2023, enacted 20 May 2023, see https://leg.colorado.gov/bills/HB23-1247; and Scott Weiser, "Nuclear power generation renaissance underway -- and Colorado may join in", *Denver Gazette*, 14 May 2023, see https://denvergazette.com/news/business/nuclear-power-generation-renaissance-underway/article_9f8a4810-eb75-11ed-9160-d312d42629c7.html, both accessed 11 August 2023.

713 - Connecticut General Assembly, "An Act Exempting Existing Nuclear Power Generating Facilities in the State from the Nuclear Power Facility Construction Moratorium", House Bill No. 5202 introduced 23 February 2022, Public Act No. 22-76 enacted 24 May 2022, see https://www.cga.ct.gov/asp/cgabillstatus/cgabillstatus.asp?selBillType=Bill&which_year=2022&bill_num=5202, accessed 8 August 2023.

714 - Environment, Energy and Technology Committee, "House Bill 96", House of Representatives, State of Idaho, House Bill No. 96, introduced 7 February 2023, enacted 14 March 2023, see https://legislature.idaho.gov/sessioninfo/2023/legislation/h0096/, accessed 27 July 2023.

715 - Indiana General Assembly, "Senate Bill 271—Small modular nuclear reactors", introduced 10 January 2022, enacted 18 March 2022, see https://iga.in.gov/legislative/2022/bills/senate/271/details; *and Nuclear News*, "Indiana SMR bill signed into law", *Nuclear Newswire*, American Nuclear Society, 22 March 2022, see https://www.ans.org/news/article-3780/indiana-smr-bill-signed-into-law/; both accessed 11 August 2023.

to increase the generation capacity from 350 MW to 470 MW[716], an obvious move to accommodate Rolls Royce's design that is aiming at precisely 470 MW.[717]

- **Ohio:** Legislators passed a budget bill (HB33) in 2023, which created the Ohio Nuclear Development Authority (ONDA), in order to foster the development of "advanced reactors" and associated supply chain manufacturing and fuel production facilities.[718] Governor Mike DeWine exercised a line-item veto to zero out the budget for ONDA and to delete portions of the ONDA provision that he deemed to conflict with Ohio's regulatory relationship with the NRC and that would have constrained his authority to make appointments of ONDA's members.[719] DeWine left the door open to establishing the authority under the state's Department of Health, which has an existing Agreement State Authority arrangement with the NRC.
- **Tennessee:** Governor Bill Lee issued an executive order in May 2023 creating the Tennessee Nuclear Energy Advisory Council to expand the nuclear industry and "advance Tennessee's ability to lead the nation in nuclear energy."[720] Grant-making and other assistance activities of the council in favor of nuclear power-related business in the state will be supported by a US$50 million Nuclear Fund established by the state legislature in the 2023–2024 budget. In July 2023, Gov. Lee announced the appointments of the members of the council.[721]
- **Virginia:** The General Assembly enacted a proposal in 2023 promoted by Gov. Glen Youngkin to create a Virginia Power Innovation Fund (VPIF) and an associated Virginia Power Innovation Program (VPIP).[722] The US$10 million VPIF would fund research and development into nuclear and other energy technologies. US$5 million would be allocated to the VPIP, for research and development of SMRs and nuclear workforce training.[723]
- **West Virginia:** Legislators repealed the state's ban on construction of nuclear power plants—enacted since 1996—in early 2022.[724]

716 - Indiana General Assembly, "Senate Bill 176—Small modular nuclear reactors", introduced 9 January 2023, enacted 20 April 2023, see https://iga.in.gov/legislative/2023/bills/senate/176/details, accessed 29 July 2023.

717 - Rebecca Thiele, "Bill changes small nuclear reactor law to accommodate Rolls Royce technology", *WFYI Public Media*, 31 January 2023, see https://www.wfyi.org/news/articles/bill-changes-small-nuclear-reactor-law-to-accommodate-rolls-royce-technology, accessed 20 August 2023.

718 - Kathiann M. Kowalski, "Ohio proposal seeks to promote advanced nuclear power", *Energy News Network*, 6 June 2023, see http://energynews.us/2023/06/06/ohio-budget-amendment-seeks-to-study-and-promote-advanced-nuclear-power/, accessed 5 August 2023.

719 - Larry Limpf, "Group glad to see nuclear development proposal vetoed", *The Press*, 7 July 2023, see https://www.presspublications.com/content/group-glad-see-nuclear-development-proposal-vetoed, accessed 5 August 2023.

720 - Governor Bill Lee, "Gov. Lee Issues Executive Order to Advance Nuclear Energy Innovation & Investment", Press Release, Governor of Tennessee, 16 May 2023, see https://www.tn.gov/governor/news/2023/5/16/gov--lee-issues-executive-order-to-advance-nuclear-energy-innovation---investment.html, accessed 26 July 2023.

721 - Governor Bill Lee, "Gov. Lee Names Tennessee Nuclear Energy Advisory Council Appointees", Governor of Tennessee, 13 July 2023, see https://www.tn.gov/governor/news/2023/7/13/gov--lee-names-tennessee-nuclear-energy-advisory-council-appointees.html, accessed 26 July 2023.

722 - Virginia General Assembly, "Senate Bill No. 1464", introduced 16 January 2023, enacted 24 March 2023, see https://lis.virginia.gov/cgi-bin/legp604.exe?231+ful+SB1464, accessed 5 August 2023.

723 - Charlie Paullin, "Virginia General Assembly split on whether to pursue nuclear power more aggressively", *Virginia Mercury*, 13 March 2023, see https://www.virginiamercury.com/2023/03/13/virginia-general-assembly-split-on-whether-to-pursue-nuclear-power-more-aggressively/, accessed 26 July 2023.

724 - West Virginia Legislature, "West Virginia - Senate Bill 4", introduced in Senate 12 January 2022, 31 January 2022, see https://www.wvlegislature.gov/Bill_Status/Bills_history.cfm?input=4&year=2022&sessiontype=RS&btype=bill, accessed 6 August 2023.

In addition to the measures taken by state governments, at least nine utilities serving eighteen states have initiated feasibility and/or siting studies, entered into partnerships with reactor developers, and/or included reactor construction in their most recent IRPs.

- In 2022, **Duke Energy** and **Purdue University** in Indiana formed a partnership to consider developing an SMR to provide power to the university.[725] They published an "interim report" in May 2023, which posits "small modular reactors as one of the most promising emerging technologies," recommends further exploration in subsequent phases of the feasibility study, and puts forward an agenda of policies, programs, and investments.[726]
- **Nebraska Public Power District**, the state's largest utility, launched a study in January 2023 to evaluate prospective sites for SMRs.[727] The study is funded by the state, with US$1 million of unspent COVID-19 pandemic relief monies from the federal government.[728] The legislature is also considering a proposal[729] backed by **Omaha Public Power District** and, allegedly, other public power utilities, to form a special legislative committee that would study the feasibility of SMRs in Nebraska.[730]
- In the integrated resource plan it submitted in 2023 to public utility commissions in the six states where its utilities operate, **Pacificorp** included construction of two more nuclear power plants or 1 GW of "advanced nuclear",[731] in addition to the Natrium project on which it is partnering with TerraPower.732 It noted that the additional reactors could be built near two coal power plants in Utah.
- **Tennessee Valley Authority** (TVA), the federal utility that provides power to seven states, is developing its Clinch River site as an Advanced Nuclear Reactor Technology Park,[733] and CEO John Lyash has stated in October 2022 that the utility must develop 20 SMRs in

725 - Purdue University and Duke Energy, "Purdue and Duke Energy to explore potential for clean, nuclear power source for campus", as released by Purdue University, 27 April 2022, see https://www.purdue.edu/newsroom/releases/2022/Q2/purdue-and-duke-energy-to-explore-potential-for-clean,-nuclear-power-source-for-campus.html, accessed 27 July 2023.

726 - Purdue University and Duke Energy, "Feasibility study: Advanced nuclear technology is a potential option to achieve zero carbon emissions for Purdue University", Press Release, 10 May 2023, see https://news.duke-energy.com/releases/feasibility-study-advanced-nuclear-technology-is-a-potential-option-to-achieve-zero-carbon-emissions-for-purdue-university; and Purdue University and Duke Energy, "Small Modular Reactor and Advanced Reactor—Feasibility Study Interim Report", May 2023, see https://www.purdue.edu/administrative-operations/nuclear/documents/smr-feasibility-study-interim-report.pdf; both accessed 13 August 2023.

727 - NPPD, "NPPD beginning Siting Study for Small Modular Nuclear Reactors", Press Release, Nebraska Public Power District, 13 January 2023, see https://www.nppd.com/press-releases/nppd-beginning-siting-study-for-small-modular-nuclear-reactors; and Nancy Gaarder, "Nebraska Public Power District to study sites for new nuclear plant in Nebraska", *Omaha World-Herald*, 13 January 2023, see https://omaha.com/news/state-regional/nebraska-public-power-district-to-study-sites-for-new-nuclear-plant-in-nebraska/article_220311dc-936f-11ed-b544-27c346f2e6fe.html; both accessed 13 August 2023.

728 - *WNN*, "Nebraska begins SMR siting study", *World Nuclear News*, 16 January 2023, see https://www.world-nuclear-news.org/Articles/Nebraska-begins-SMR-siting-study, accessed 16 January 2023.

729 - State Senator Tom Brewer, "Sen. Tom Brewer: Small Modular Nuclear Reactors", *Star-Herald*, 23 July 2023, see https://starherald.com/news/community/hemingford/sen-tom-brewer-small-modular-nuclear-reactors/article_d82ddcae-fa89-11ed-a964-57a36ad3d3fd.html, accessed 27 July 2023.

730 - Chris Dunker, "Special committee proposed to study small modular nuclear reactors in Nebraska", *Lincoln Journal Star*, 24 February 2023, see https://journalstar.com/news/state-and-regional/govt-and-politics/special-committee-proposed-to-study-small-modular-nuclear-reactors-in-nebraska/article_2239fce0-b482-11ed-8e1a-971ee03d691e.html, accessed 27 July 2023.

731 - PacifiCorp, "2023 Integrated Resource Plan—Volume I", filed 31 March 2023, see https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/integrated-resource-plan/2023-irp/2023_IRP_Volume_I.pdf; and PacifiCorp Sites, "PacifiCorp's 2023 plan advances a net-zero future", Rocky Mountain Power, 31 March 2023, see http://www.rockymountainpower.net/about/newsroom/news-releases/2023-integrated-resource-plan.html; both accessed 13 August 2023.

732 - TerraPower, "TerraPower, Wyoming Governor & PacifiCorp announce efforts to advance nuclear technology in Wyoming—Natrium™ Reactor Demonstration Project will bring clean energy and jobs to the state", Press Release, 2 June 2021, see https://www.terrapower.com/natrium-demo-wyoming-coal-plant/, accessed 5 August 2023.

733 - TVA, "Advanced Nuclear Solutions", Tennessee Valley Authority, Undated, see https://www.tva.com/energy/technology-innovation/advanced-nuclear-solutions, accessed 13 August 2023.

order to reach its 2050 emissions goal.[734] It received an Early Site Permit from NRC in 2019 for the construction of an SMR project of 800 MW of generation capacity, of unspecified design.[735] The utility completed a programmatic environmental impact statement (PEIS) in October 2022, which concluded that, of the options it evaluated, the "Preferred Alternative" is the development of the site with SMRs and/or advanced non-LWRs.[736] A few months earlier, TVA announced that it had selected GE-Hitachi's BWRX-300 design for the first reactor project at Clinch River,[737] for which site preparation and a construction permit application are now underway and, in March 2023, it formed a partnership with GE-Hitachi, Ontario Power Generation, and Poland-based Synthos Green Energy to develop the reactor design internationally.[738]

- **Dominion Energy** filed its most recent IRP with the Virginia Corporations Commission in May 2023. The plan includes an expanded role for new reactors, on a more rapid implementation schedule. Instead of planning to bring the first of four SMRs online in 2042, Dominion now projects to build at least six SMRs totaling 1.6 GW of capacity, with the first project coming online in 2034.[739]
- **Energy Northwest** (ENW) and **X-energy** announced in July 2023 that they have signed an agreement to jointly develop up to twelve Xe-100 reactors with a total capacity of 960 MW at ENW's Columbia Generating Station in Richland, Washington, adjacent to the DOE's Hanford Nuclear Site. The first module is scheduled to be online by 2030.[740]
- **Dairyland Power Cooperative** in Wisconsin entered into an agreement with NuScale in 2022 to consider building SMRs, and to "support Dairyland's due diligence process in evaluating affordable, reliable and carbon-free energy solutions."[741]

The relatively small amounts of funds that states have appropriated to date, and the prevailing approach among utilities to undertake studies and to include new reactors in long range

734 - William Freebairn, "TVA needs 20 new nuclear units to decarbonize by 2050, CEO says", *Platts Megawatt Daily*, 25 October 2022.

735 - U.S. NRC, "Issued Early Site Permit - Clinch River Nuclear Site", U.S. Nuclear Regulatory Commission, Updated 21 September 2022, see https://www.nrc.gov/reactors/new-reactors/large-lwr/esp/clinch-river.html, accessed 6 August 2023.

736 - TVA, "Clinch River Nuclear Site Advanced Nuclear Reactor Technology Park Final Programmatic Environmental Impact Statement", Notices, Federal Register, Vol. 87, No. 190, 3 October 2022, see https://www.federalregister.gov/documents/2022/10/03/2022-21319/clinch-river-nuclear-site-advanced-nuclear-reactor-technology-park-final-programmatic-environmental, accessed 29 July 2023.

737 - *Nuclear News*, "TVA, GEH advance SMR plans for Clinch River site", *Nuclear Newswire*, 8 August 2022, see https://www.ans.org/news/article-4200/tva-geh-advance-smr-plans-for-clinch-river-site/, accessed 29 July 2023.

738 - TVA, "Tennessee Valley Authority, Ontario Power Generation, and Synthos Green Energy Invest in Development of GE Hitachi Small Modular Reactor Technology", Press Release, Tennessee Vallay Authority, 23 March 2023, see https://www.tva.com/newsroom/press-releases/tennessee-valley-authority-ontario-power-generation-and-synthos-green-energy-invest-in-development-of-ge-hitachi-small-modular-reactor-technology, accessed 28 July 2023.

739 - Dominion Energy, "Virginia Electric and Power Company—2023 Integrated Resource Plan", filed 1 May 2023, see https://cdn-dominionenergy-prd-001.azureedge.net/-/media/pdfs/global/company/2023-va-integrated-resource-plan.pdf?la=en&rev=577d8ea0481e446e98fe4dfa6436fc50; and Steve Haner, "Dominion Changes Course on Natural Gas, SMR Nukes", Thomas Jefferson Institute for Public Policy, as published in *The Roanoke Star News*, 3 May 2023, see https://theroanokestar.com/2023/05/03/dominion-changes-course-on-natural-gas-smr-nukes/, also Diana DiGangi, "Dominion Energy projects adding up to 9 GW of gas-fired capacity in Virginia to bolster reliability", *Utility Dive*, 4 May 2023, see https://www.utilitydive.com/news/dominion-virginia-resource-plan-reliability-natural-gas-coal-renewables-youngkin/649377/, all accessed 13 August 2023.

740 - X-energy and Energy Northwest, "Energy Northwest and X-energy Sign Joint Development Agreement for Xe-100 Advanced Small Modular Reactor Project", Press Release, as released by X-energy, 19 July 2023, see https://x-energy.com/media/news-releases/energy-northwest-x-energy-joint-development-agreement-xe-100; and Larry Pearl, "Energy Northwest, X-energy sign joint development agreement for up to 12 small modular reactors", *Utility Dive*, 20 July 2023, see https://www.utilitydive.com/news/energy-northwest-x-energy-xe-100-nuclear-small-modular-reactor/688460/, accessed 27 July 2023.

741 - Nuscale and Dairyland Power Cooperative, "NuScale Power and Dairyland announce MOU to evaluate potential technology", Press Release, 24 February 2022, see https://www.dairylandpower.com/nuscale-power-and-dairyland-announce-mou-evaluate-potential-technology, accessed 27 July 2023.

planning—rather than proposing specific projects, seeking permits and regulatory approvals, and inking contracts with suppliers—reflects more caution than the rush to project approvals by utility commissions and the submissions of 28 NRC license applications that occurred in the wake of EPACT 2005, the last time nuclear energy received a major infusion of federal support. Reasons for caution include:

- From 2005 through 2008, natural gas and wholesale electricity prices were surging to economically unsustainable levels nationwide, which made the then-projected costs of new reactors appear competitive.
- Prior to 2010, the most dramatic cost reductions and performance improvements of wind, solar, and battery storage, had not yet occurred. Now, even low-end projections for SMRs and non-LWRs are not competitive (see Nuclear Economics and Finance).
- Large, sustained reductions in natural gas and wholesale electricity prices since 2009, with the advent of abundant, low-cost natural gas production via horizontal, high-pressure hydraulic fracturing, continue to pressure margins.
- The massive failure of the past decade's nuclear development efforts in the U.S. and Europe is still fresh enough that it has tempered the response of policymakers and utility executives to the ebullient promotion of SMRs and non-LWRs.

It is uncertain if the current interest in new nuclear will be sustained if the small handful of demonstration projects that are receiving direct support from the DOE do not succeed. While the DOE is supporting a larger number of private sector research, development, and demonstration (RD&D) projects,[742] there are only three commercial reactor projects with concrete plans for construction and projected commercial operation dates around 2030:

- **NuScale's Carbon Free Power Project (CFPP):** a six-reactor, 462-MW SMR power plant that was to be constructed at the DOE's Idaho National Laboratory (INL), with US$1.355 billion in cost-sharing support. NuScale projected the first reactor to be online in 2029, and the remainder in 2030.[743] However, on 8 November 2023, NuScale announced the termination of the project (see dedicated section in the chapter on SMRs).
- **TerraPower's Natrium project:** a 345-MW fast-neutron reactor based on GE-Hitachi's PRISM design, with a 150-MW molten salt thermal storage loop, to be built at a coal power plant site in Kemmerer, Wyoming, with US$2 billion in DOE cost-sharing support[744] and in partnership with PacifiCorp, a utility subsidiary of Berkshire Hathaway Energy. Originally scheduled to be online in 2028, TerraPower announced in December 2022 that the project will be delayed until at least 2030, since "Russia's invasion of Ukraine caused the only

742 - Office of Nuclear Energy, "Energy Department's Advanced Reactor Demonstration Program Awards $30 Million in Initial Funding for Risk Reduction Projects", Press Release, U.S. Department of Energy, 16 December 2020, see https://www.energy.gov/ne/articles/energy-departments-advanced-reactor-demonstration-program-awards-30-million-initial; and Office of Nuclear Energy, "Energy Department's Advanced Reactor Demonstration Program Awards $20 million for Advanced Reactor Concepts", Press Release, U.S. Department of Energy, 22 December 2020, see https://www.energy.gov/ne/articles/energy-departments-advanced-reactor-demonstration-program-awards-20-million-advanced; both accessed 17 August 2023.

743 - Carbon Free Power Project, "CFPP LLC", Updated 2023, see https://www.cfppllc.com/; and UAMPS, "DOE cost-share award of $1.355 billion is approved for UAMPS' Carbon Free Power Project", Utah Associated Municipal Power Systems, Press Release, 16 October 2020, see https://www.uamps.com/file/41df5556-8f47-47c3-af10-d3665271fd20; both accessed 13 August 2023.

744 - TerraPower, "TerraPower selects Kemmerer, Wyoming as the preferred site for advanced reactor demonstration plant", Press Release, 16 November 2021, see https://www.terrapower.com/natrium-demo-kemmerer-wyoming/, accessed 5 August 2023.

commercial source of HALEU [High Assay Low Enriched Uranium] fuel to no longer be a viable part of the supply chain for TerraPower."[745]

- **X-energy's Seadrift project:** a four-reactor 320-MW power plant using the Xe-100 high-temperature, gas-cooled SMR design, to provide electricity and process heat at Dow Chemical's UCC Seadrift Operations manufacturing site in Texas, with US$1.2 billion in DOE cost-sharing support. As of May 2023, construction was projected to begin in 2026 and be completed by 2030.[746]

As detailed in the chapter on SMRs, all of these projects face significant regulatory, technical, and financial hurdles. For several years, much of the political debate about the long construction time and delays has been framed as a matter of undue "regulatory burden" imposed by the NRC through excessive regulation and inefficient licensing processes that have not kept up with the pace of innovation within the industry. Congress has enacted several pieces of legislation to help the industry's fortunes, most notably, the Nuclear Energy Innovation and Modernization Act (NEIMA), in 2019.[747] NEIMA requires the NRC to implement a new set of regulations for licensing "advanced reactors" that is "risk-informed" and "technology-inclusive" before 31 December 2027.

That would already be an ambitious target date to produce a single set of regulations for licensing the wide array of commercial reactor designs being developed by industry with support from DOE, many of which involve design features, fuel types, and coolants that the NRC has not had to review before in a licensing context. In response to pressure from Congress, the NRC Commissioners directed their staff to set a goal of promulgating the new set of licensing regulations two years earlier than NEIMA requires, initially by October 2024,[748] and later extended to July 2025.[749] Referred to as 10 CFR Part 53 (or just Part 53) for the chapter they would occupy in the NRC's federal regulations, the NRC staff submitted the 1,300-page draft regulation to the Commission in March 2023.[750] Once the Commission has completed its review, it must publish the proposed regulations and open up a public comment period, then review the feedback that is submitted, and finalize the regulations, before the commission votes to adopt them.

745 - Caitlin Tan, "The opening of TerraPower's nuclear plant in Kemmerer will be delayed by two years", *Wyoming Public Radio*, 14 December 2022, see https://www.wyomingpublicmedia.org/natural-resources-energy/2022-12-14/the-opening-of-terrapowers-nuclear-plant-in-kemmerer-will-be-delayed-by-two-years, accessed 5 August 2023.

746 - X-energy and Dow, "Dow and X-energy Advance Efforts to Deploy First Advanced Small Modular Nuclear Reactor at Industrial Site Under DOE's Advanced Reactor Demonstration Program", Press Release, 1 March 2023, see https://x-energy.com/media/news-releases/dow-and-x-energy-advance-efforts-to-deploy-first-advanced-small-modular-nuclear-reactor-at-industrial-site-under-does-advanced-reactor-demonstration-program; and X-energy and Dow, "Dow's Seadrift, Texas location selected for X-energy advanced SMR nuclear project to deliver safe, reliable, zero carbon emissions power and steam production", Press Release, 11 May 2023, see https://corporate.dow.com/en-us/news/press-releases/dow-s-seadrift--texas-location-selected-for-x-energy-advanced-sm.html; accessed 20 August 2023.

747 - Environment and Public Works Committee, "S.512 - Nuclear Energy Innovation and Modernization Act", United States Congress, introduced 2 March 2017, Public Law No. 115-439 enforced 14 January 2019, see http://www.congress.gov/bill/115th-congress/senate-bill/512, accessed 8 August 2023.

748 - U.S. NRC, "Memorandum: Staff Requirements – SECY-20-0032 – Rulemaking Plan on 'Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors (RIN-3150-AK31; NRC-2019-0062)'", U.S. Nuclear Regulatory Commission, 2 October 2020, see https://www.nrc.gov/docs/ML2027/ML20276A293.pdf, accessed 20 October 2023.

749 - U.S. NRC, "Non-Light-Water Reactor Implementation Action Plan—Progress Summary and Future Plans", U.S. Nuclear Regulatory Commission, 31 January 2022, see https://www.nrc.gov/docs/ML2133/ML21337A378.pdf, accessed 21 September 2023.

750 - U.S. NRC, "Part 53 – Risk Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors", U.S. Nuclear Regulatory Commission, 9 March 2023, see https://www.nrc.gov/reactors/new-reactors/advanced/rulemaking-and-guidance/part-53.html, accessed 6 August 2023.

The NRC intends to issue the final rule by July 2025[751],but that would likely still be too late for the NuScale, TerraPower, and X-energy projects to seek licenses under the new standards and still bring the reactors online in 2030. While Part 53 will ostensibly have a more flexible set of regulatory standards for reviewing license applications that can apply to any type of commercial reactor, applying for a license and completing construction in under five years is hardly conceivable. For these reasons, the demonstration projects are pursuing licenses under existing regulatory options: Part 50 and Part 52.

The Part 52 regulations that the NRC adopted more than 30 years ago were intended to create a more streamlined licensing process. Under Part 52, reactor developers can seek design certification (DC) or Standard Design Approval (SDA), which goes through NRC's technical safety review.[752] Once a design is certified, a company that wants to build a new nuclear power plant can seek a combined Construction and Operating License (COL) by submitting an application that references the DC or the SDA, thereby precluding the need for a complete technical safety review of the application. Further, Part 52 allows for some construction work to begin before NRC issues the COL: through issuance of a Limited Work Authorization (LWA), the prospective licensee can begin site preparation work. Of the 14 COLs that the NRC issued in the previous decade, the reviews for Vogtle-3 and -4 and Summer-2 and -3 were the most rapid, being completed in around four years.

This is the process that NuScale had been using for the CFPP. The company submitted the 50-MW VOYGR SMR for design certification in 2016, which the NRC approved with three exceptions in 2020.[753] The CFPP probably could have submitted a COL application at that time, but for two issues as noted in the chapter on SMRs:

- NuScale was unable to resolve three outstanding safety problems that the NRC's Advisory Committee on Reactor Safeguards found in its review—most significantly, with the design of the steam generators. In January 2023, the NRC issued the DC and completed its addition to the Part 52 regulations, with the three identified issues still unresolved.[754] It is the first time the NRC issued what is essentially a partial DC. Any COL application that referenced the design would have to resolve the problems with the steam generators in the application, those aspects of which would undergo the requisite technical review.
- Since submitting the DC application for the original 50-MW design and its 12-reactor, 600 MW plant configuration, NuScale has uprated the reactor twice—first to 60 MW,[755]

751 - Ibidem.

752 - U.S. NRC, "Regulations—10 CFR, Part 52–Licenses, Certifications, and Approvals for Nuclear Power Plants", United States Nuclear Regulatory Commission, Updated 21 February 2023, see https://www.nrc.gov/reading-rm/doc-collections/cfr/part052/full-text.html, accessed 13 August 2023.

753 - U.S. NRC, "Standard Design Approval for the NuScale Power Plant Based on the Nuscale Standard Plant Design Certification Application", Docket No. 52-048, United States Nuclear Regulatory Commission, 11 September 2020, see https://www.nrc.gov/docs/ML2024/ML20247J564.pdf, accessed 13 August 2023.

754 - U.S. NRC, "NuScale Small Modular Reactor Design Certification", 10 CFR Part 52, Rules and Regulations, Federal Register, Vol. 88, No. 12, see https://www.govinfo.gov/content/pkg/FR-2023-01-19/pdf/2023-00729.pdf, accessed 13 August 2023.

755 - NuScale, "Breakthrough for NuScale Power: Increase in Its SMR Output Delivers Customers 20 Percent More Power", Press Release, 6 June 2018, see https://www.nuscalepower.com/en/news/press-releases/2018/increase-in-its-smr-output-delivers-customers-20-percent-more-power, accessed 13 August 2023.

> then to 77 MW[756]—and downsized the plant to a six-reactor, 462-MW configuration. The capacity uprates likely raised the need to review further aspects of the reactor's design, in addition to the steam generators. The structural changes to the reactor building, with more powerful reactors housed within possibly a smaller structure, would require technical review, as well.

NuScale lost seven years in the licensing process due to design changes that it has made for reasons totally unrelated to NRC's licensing regulations. It could have submitted a COL application for the CFPP in late 2020, after NRC issued its partial approval of the 50-MW, 12-reactor design. If it had, it could have been on a path to receive a COL and begin construction by the end of 2024.

Now, the CFPP is essentially starting over, with the submission of the new SDA application in several transmittals at the end of 2022.[757] In order to meet its 2030 construction schedule, NuScale is proposing an unusual licensing process that requires exemptions from Part 52. The company submitted an LWA application on 31 July 2023, along with an exemption request to permit construction of excavation wall shoring for the reactor and radioactive waste buildings.[758] It would then submit a COL application in January 2024 that references the SDA before the NRC has approved it. Under its proposed plan, NuScale has told NRC that it believes the SDA review could be completed in 2024, the LWA issued in August 2025, and the COL to be issued in July 2026.[759] The NRC projected the SDA review to take until mid-2025,[760] but that may not matter as long as it issues the SDA before the rest of the COL review is complete.

Assuming that all had gone to plan, before the entire project was terminated in early November 2023, NuScale was counting on an ambitious construction schedule unmatched in the U.S. industry:[761]

- beginning site preparation work in the second half of 2025;
- starting reactor construction in the second half of 2026;
- completing construction of the reactor building and common structures, systems, and components, and installing the first reactor, all in a little over three years (mid-2026 to late-2029); and

756 - NuScale, "NuScale Power Announces an Additional 25 Percent Increase in NuScale Power Module™ Output; Additional Power Plant Solutions; Meeting Canada's Needs", Press Release, 10 November 2020, see https://www.nuscalepower.com/en/news/press-releases/2020/nuscale-power-announces-an-additional-25-percent-increase-in-nuscale-power-module-output, accessed 13 August 2023.

757 - U.S. NRC, "NuScale Power, LLC—Standard Design Approval Application; Receipt", Docket Nos. 05200050 and 99902078, NRC-2023-0027, 13 March 2023, see https://www.nrc.gov/docs/ML2301/ML23018A015.pdf, accessed 14 August 2023.

758 - CFPP, "Submittal of CFPP LLC Carbon Free Power Project (CFPP) Application for Limited Work Authorization", Docket No. 99902052, submitted to U.S. Nuclear Regulatory Commission, 25 July 2023, see https://www.nrc.gov/docs/ML2321/ML23212A008.pdf, accessed 13 August 2023.

759 - NuScale, "NuScale Power, LLC Submittal on Behalf of CFPP LLC Carbon Free Power Project (CFPP) Combined License Application (COLA) Entitled, 'Carbon Free Power Project (CFPP) Regulatory Engagement Plan For Early Construction,' PL-135470-P, PL-135470-NP, Revision 0", Docket No. 99902052, submitted to U.S. NRC, 22 March 2023, see https://www.nrc.gov/docs/ML2308/ML23081A094.pdf; and CFPP, "Project Milestones", 2023, see https://www.cfppllc.com/; both accessed 13 August 2023.

760 - U.S. NRC, "NuScale US460 Standard Design Approval Application Review", United States Nuclear Regulatory Commission, 1 August 2023, see https://www.nrc.gov/reactors/new-reactors/smr/licensing-activities/current-licensing-reviews/nuscale-us460.html, accessed 6 August 2023.

761 - CFPP, "Carbon Free Power Project—Application for Limited Work Authorization", Revision 0, July 2023, see https://www.nrc.gov/docs/ML2321/ML23212A009.pdf, accessed 19 August 2023.

- installing the remaining five reactors in the same building within one year (end-of-year 2030).

TerraPower and X-energy, by contrast, do not plan to pursue licenses for their demonstration reactors under Part 52. Neither has applied for DC or SDA for their reactor designs. They are currently involved in pre-application discussions with the NRC[762] to submit license applications through Part 50, which allows construction to begin with the issuance of a permit before the detailed safety review for the license is complete.

While this approach does not provide a DC or SDA that subsequent Natrium or Xe-100 license applicants could use to apply for a COL, it could enable the demonstration projects to begin construction in or around 2025, and to proceed in parallel with the review of the license application. The companies would then have to complete construction and receive licenses within about five years in order to be online in 2030. Similar promises have been made in the past but never achieved in the western world, at least not in the past several decades.

Extended Reactor Licenses

Under the Atomic Energy Act (AEA) of 1954, as amended, and NRC regulations, the NRC issues initial operating licenses for commercial power reactors for 40 years. NRC regulations permit license renewals that extend the initial 40-year license for up to 20 additional years per renewal.

As of 31 July 2023, 84 of the 93 operating U.S. units had already received 20-year Initial License Renewals, which permits reactor operation beyond 40 and up to 60 years. Since December 2019, the Nuclear Regulatory Commission (NRC) has not issued any additional 20-year license renewals.[763] Two reactors (Comanche Peak-1 and -2) applied for license extensions in 2022, for which a decision is expected in September 2024. One additional application (Perry-1) is under application review.[764] The owners of three other reactors (Diablo Canyon-1 and -2, Clinton-1) plan to submit applications in late 2023 and early 2024.

The remaining operating reactors are Watts Bar-1 and-2, which began operation in 1996 and 2016 respectively; and Vogtle-3, which entered commercial operation only in July 2023.

In July 2017, the NRC published a final document describing "aging management programs" that allow the NRC to grant nuclear power plants operating licenses for up to 80 years, which the NRC has designated "Subsequent License Renewal."[765] As of 31 July 2023, the NRC had

762 - U.S. NRC, "Pre-Application Activities for Advanced Reactors", U.S. Nuclear Regulatory Commission, Updated 4 August 2023, see https://www.nrc.gov/reactors/new-reactors/advanced/licensing-activities/pre-application-activities.html, accessed 14 August 2023.

763 - U.S. NRC, "Status Of Initial License Renewal Applications And Industry Initiatives", Updated 10 August 2023, U.S. Nuclear Regulatory Commission, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 14 August 2023.

764 - U.S. NRC, "Comanche Peak Nuclear Power Plant Units 1 and 2 – License Renewal Application", U.S. Nuclear Regulatory Commission, Updated 20 June 2023, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/comanche-peak.html, accessed 1 August 2023.

765 - Office of Nuclear Reactor Regulation, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report", Final Report, NUREG-2191, Vol. 2, U.S. NRC, July 2017, see https://www.nrc.gov/docs/ML1718/ML17187A204.pdf, accessed 10 June 2020.

granted Subsequent Renewed Operating Licenses to six reactors,[766] which would permit operation from 60 to 80 years. Applications for a further ten reactors are under review,[767] and submissions of applications for a further nine reactors are currently expected progressively until the end of 2025.[768]

"the NRC issued an unprecedented order effectively suspending the subsequent license approvals it had granted for four reactors"

However, in February 2022, the NRC issued an unprecedented order effectively suspending the subsequent license approvals it had granted for four reactors,[769] and holding approvals of the other applications in abeyance, while it develops a new environmental assessment for license renewals authorizing operation from 60 to 80 years. Intervenors in the reviews of the Turkey Point and Peach Bottom applications alleged to the NRC that it had violated its own regulations and the National Environmental Policy Act (NEPA) by approving the Subsequent License Renewals on the basis of an inapplicable Generic Environmental Impact Statement (GEIS). Prior, in a ruling issued on 12 November 2020, the NRC upheld its decision granting the licenses, stating that it was correct to rely on NRC's Generic Environmental Impact Statement for license renewal.[770] However, two of the NRC Commissioners dissented from the decision, arguing this interpretation violates the NRC's obligations under NEPA.[771] As a result of the expiration of two Commissioners' terms in 2021, the dissenting commissioners then held the majority by two to one, and determined to avoid legal challenges in the courts by suspending the previous approvals. Subject to the Commission's February 2022 orders, the environmental review of Subsequent License Renewal applications for the four already-approved reactors and all other applications under review were suspended.

When the NRC promulgated its rules for review of initial 20-year license renewals in 1996, NRC fulfilled its NEPA obligations by publishing a GEIS[772] (updated in 2013)[773], covering a broad

766 - Turkey Point-3 and -4 (2019), Peach Bottom-2 and -3 (2020), and Surry-1 and -2 (2021).
See U.S. NRC, "Status of Subsequent License Renewal Applications", U.S. Nuclear Regulatory Commission, Updated 6 July 2023, see https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html, accessed 13 August 2023.

767 - North Anna-1 and -2; Oconee-1, -2, and -3; Point Beach-1 and -2; St. Lucie-1 and -2, and Monticello-1.
See U.S. NRC, "Status of Subsequent License Renewal Applications", Updated 6 July 2023, op. cit.

768 - Browns Ferry-1, -2 and -3, VC Summer-1, Dresden-2 and -3, Robinson-2, and Hatch-1 and 2.
See U.S. NRC, "Status of Subsequent License Renewal Applications", Updated 6 July 2023, op. cit.

769 - Turkey Point-3 and -4 and Peach Bottom-2 and -3. Because no intervenors challenged the subsequent license renewal application for Surry-1 and -2, the Commission did not suspend its approval in that case, even though the Surry application relied upon the same Generic Environmental Impact Statement as the other applications.
See U.S. NRC, "In the Matter of Florida Power & Light Co. (Turkey Point Nuclear Generating Units 3 and 4)—Memorandum and Order CLI-22-02", Docket Nos. 50-250-SLR and 50-251-SLR, 24 February 2022, see https://www.nrc.gov/docs/ML2205/ML22055A496.pdf; and U.S. NRC, "In the Matter of Exelon Generation Company, LLC (Peach Bottom Atomic Power Station, Units 2 and 3)—Memorandum and Order CLI-22-04", Docket Nos. 50-277-SLR and 50-278-SLR, 24 February 2022, see https://www.nrc.gov/docs/ML2205/ML22055A557.pdf; both accessed 1 September 2022.

770 - U.S. NRC, "In the Matter of Exelon Generation Company, LLC (Peach Bottom Atomic Power Station, Units 2 and 3)–Commission Memorandum and Order (CLI-20-11)", Docket Nos. 50-277-SLR and 50-278-SLR, U.S. Nuclear Regulatory Commission, 12 November 2020, see https://www.nrc.gov/docs/ML2031/ML20317A110.pdf, accessed 11 August 2021.

771 - Paul M. Bessette, Ryan K. Lighty and Scott D. Clausen, "NRC Reaffirms Its Decision Allowing SLR Applicants to Rely on License Renewal GEIS", *Up & Atom, Morgan Lewis*, 25 November 2020, see https://www.morganlewis.com/blogs/upandatom/2020/11/nrc-reaffirms-its-decision-allowing-slr-applicants-to-rely-on-license-renewal-geis, accessed 11 August 2021.

772 - Office of Nuclear Regulatory Research, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants: Appendices – Final Report", NUREG-1437, Volume 2, U.S. Nuclear Regulatory Commission, May 1996, see https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/v2/index.html, accessed 1 September 2022.

773 - U.S. NRC, "Reactor License Renewal Process— Generic Environmental Impact Statement", Updated 10 November 2020, see https://www.nrc.gov/reactors/operating/licensing/renewal/process.html#generic, accessed 1 September 2022.

array of environmental impacts that the NRC deemed common to all initial license renewals. In doing so, the NRC issued a regulation authorizing licensees to use the GEIS for initial license renewals to operate for up to 60 years. Thus, when applying for Initial License Renewal, the licensee needs only to provide a Supplemental Environmental Impact Statement, addressing impacts that are site-specific to the reactor/s in question. In the wake of the Commission's decision of February 2022, the NRC issued a new draft License Renewal GEIS in March 2023, which would cover all operating license extensions, as well as a proposed rule change that would authorize applicants to reference it in the applications.[774] NRC solicited public comments on the draft GEIS and rule change which concluded in May 2023, but the Commission has not yet issued a decision. Finalization of the updated GEIS is expected in 2024.

While not guaranteeing reactors' continued operation—average closure age has been well below 50 years in the past few years (see Figure 51 and Figure 52)—multiple applications are expected over the coming years for subsequent license renewals. For instance, Duke Energy Corporation has said it plans to seek license extensions for all 11 of its reactors.[775] Thus far, it filed applications for Oconee-1, -2, and -3 in 2021, and intends to submit an application for Robinson-2 in 2025.[776] The federal legislation providing extended financial support for reactor operations is likely to encourage additional applications for 80-year operating licenses. In particular, the combination of the Nuclear Production Tax Credits (PTC) and the availability of the Energy Infrastructure Reinvestment Financing loan guarantee program provide a foundation of subsidies and low-interest, low-risk financing that could encourage licensees to apply. However, because the Nuclear PTC expires in 2032, the industry may look for greater certainty about the longer-term availability of subsidies before making investment decisions to pursue 80-year license extensions.

774 - U.S. NRC, "License Renewal Generic Environmental Review", U.S. Nuclear Regulatory Commission, Updated 7 June 2023, see https://www.nrc.gov/reactors/operating/licensing/renewal/sled.html, accessed 7 August 2023.

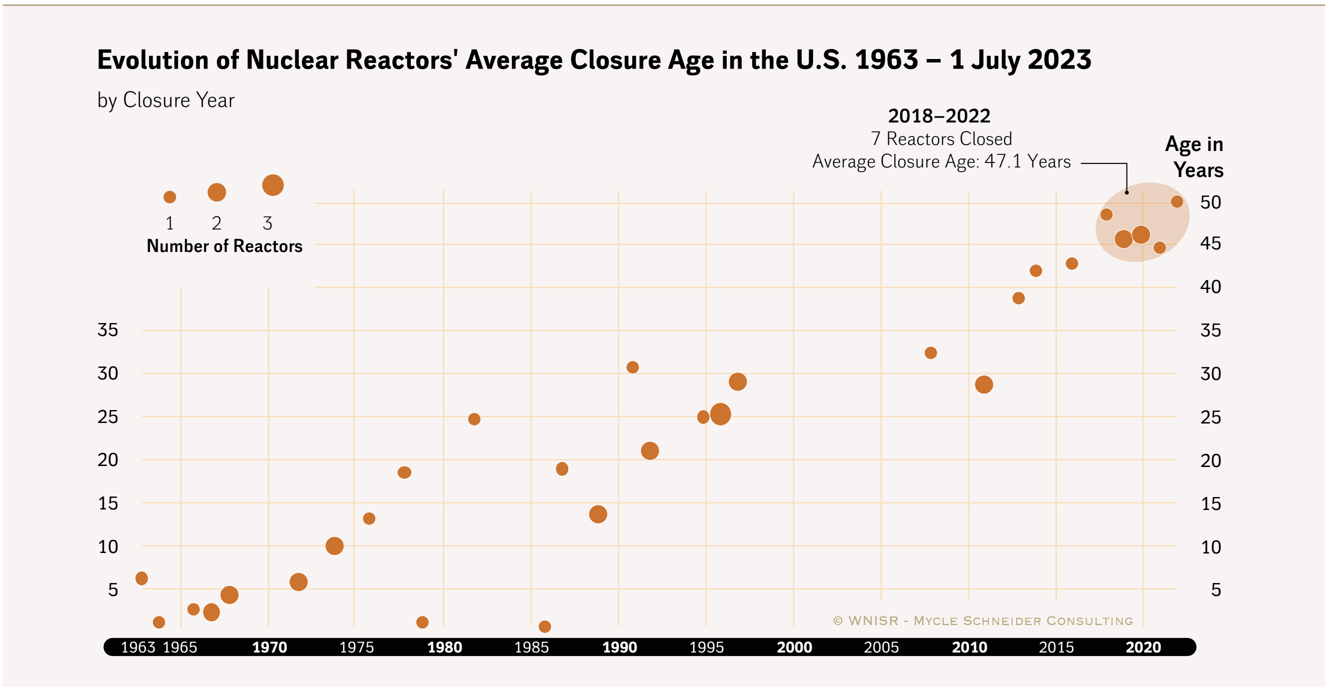
775 - Ari Natter, "The U.S. May Soon Have the World's Oldest Nuclear Power Plants", *Bloomberg*, 4 February 2020, see https://www.bloomberg.com/news/articles/2020-02-04/the-u-s-may-soon-have-the-world-s-oldest-nuclear-power-plants, accessed 2 July 2020.

776 - U.S. NRC, "Status of Subsequent License Renewal Applications", U.S. Nuclear Regulatory Commission, Updated 6 July 2023, see https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html, accessed 15 August 2023.

Reactor Closures

The average age of the seven reactors closed in the U.S. over the five-year period 2018–2022 was 47.1 years (see Figure 51), significantly below their licensed lifetimes of 60 years.

Figure 51 · Evolution of Average Reactor Closure Age in the U.S.



Sources: WNISR with IAEA-PRIS, 2023

The retirement of Palisades in May 2022[777] marked the thirteenth closure in ten years, starting with the retirements of four reactors in the first half of 2013: Crystal River-3, Kewaunee, and San Onofre-2 and -3. It also marked the completion of Entergy's planned exit from the merchant generation business, preceded by the retirements of Vermont Yankee (2014), Pilgrim (2019), Indian Point-2 (2020), and Indian Point-3 (2021), as well as the 2017 divestiture of FitzPatrick to Exelon.[778]

With the effort to extend the operation of Diablo Canyon-1 and -2, there are no further scheduled closures for this decade.

The Palisades Case

The effort by Michigan officials to bring Palisades out of retirement would also make it the first reactor in the U.S. to return to operation after entering decommissioning. The reactor's closure was preceded by a proposal in April 2022 by Michigan Governor Gretchen Whitmer to apply a federal subsidy under the DOE's Civil Nuclear Credit (CNC) program toward attracting

777 - Entergy, "Entergy's Palisades team finishes strong as facility shuts down", Press Release, 20 May 2022, see https://www.entergynewsroom.com/news/entergy-s-palisades-team-finishes-strong-as-facility-shuts-down/, accessed 14 August 2023.

778 - Entergy, "Entergy Completes Sale of James A. FitzPatrick Nuclear Power Plant to Exelon", Press Release, 31 March 2017, see https://www.entergynewsroom.com/news/entergy-completes-sale-jamesfitzpatrick-nuclear-power-plant-exelon/, accessed 13 August 2023.

a new owner who would extend the operation of Palisades.[779] Entergy had already entered into a contract to transfer ownership of Palisades and its decommissioning trust fund (DTF) to Holtec International, for the purposes of decommissioning, when Entergy's 15-year power purchase agreement with Consumers Energy expired. In the end, Entergy closed Palisades ten days early, because of leaks in the control rod drive seals that occurred as it was gradually reducing power.[780] In November 2022, DOE determined that Palisades was not eligible for the CNC,[781] but Michigan officials have persisted. Holtec has submitted an application to DOE for a US$1 billion loan guarantee to help finance a restart,[782] and it has initiated discussion with NRC about the licensing process. Gov. Whitmer and the Michigan Public Service Commission have extended the possibility of a new power purchase agreement (PPA) to underwrite Palisades' continued operation,[783] and, in June 2023, the state legislature authorized US$150 million efforts from the state's FY2024 budget to support Palisades' restart.[784]

It is unclear if this effort can ultimately succeed, given the significant obstacles Holtec and the state face.[785] Holtec has no experience operating nuclear reactors; its core businesses are in developing and manufacturing irradiated fuel storage systems and, since 2018, in managing the decommissioning of reactors. In order to meet the technical qualifications requirements for an operating license, Holtec would either have to hire an experienced nuclear operating company to manage Palisades or find one willing to take ownership of the plant entirely. Palisades is known to have a long list of maintenance needs, such as the control rod drive seals, which would require significant expense for a new owner to take on. Most of the skilled workforce that ran Palisades has retired or taken jobs elsewhere, so Holtec or a new owner would have to recruit hundreds of workers to a plant whose future is still uncertain. And because the restart of a reactor that has entered decommissioning and has no operating license is unprecedented, the NRC licensing process may take longer than expected and be subject to interventions and legal challenges.

The irony of the situation is that Palisades' retirement was decided in 2017, nearly five years in advance, but state officials took no action at the time. The rationale for the retirement

779 - Governor Gretchen Whitmer, "Whitmer Calls for Federal Investment to Protect Jobs and Shore up Energy Needs", Press Release, Office of the Governor, State of Michigan, 20 April 2022, see https://www.michigan.gov/whitmer/news/press-releases/2022/04/20/whitmer-calls-for-federal-investment-to-protect-jobs-and-shore-up-energy-needs, accessed 14 August 2023.

780 - Entergy, "Entergy's Palisades team finishes strong as facility shuts down", Press Release, 20 May 2022, see https://www.entergynewsroom.com/news/entergy-s-palisades-team-finishes-strong-as-facility-shuts-down/; and Carolyn Muyskens, "Palisades Nuclear Plant has shut down 10 days early, owners announce", *The Holland Sentinel*, 20 May 2022, see https://www.hollandsentinel.com/story/news/local/2022/05/20/palisades-nuclear-plant-shut-down-10-days-early-owners-announce/9862288002/, both accessed 14 August 2023.

781 - Timothy Gardner, "U.S. rejects funding to re-open Michigan nuclear plant -Holtec", *Reuters*, 18 November 2022, see https://www.reuters.com/business/energy/us-rejects-funding-re-open-michigan-nuclear-plant-holtec-2022-11-18/, accessed 7 August 2023.

782 - Sheri McWhirter, "Granholm 'hopeful' about $1B in federal loans to restart Palisades nuclear plant", *MLive*, 15 May 2023, see https://www.mlive.com/public-interest/2023/05/granholm-hopeful-about-1b-in-federal-loans-to-restart-palisades-nuclear-plant.html, accessed 7 August 2023.

783 - Governor Gretchen Whitmer, "Whitmer Announces Plan with Holtec to Reopen Palisades Plant", Press Release, Office of the Governor, State of Michigan, 9 September 2022, see https://www.michigan.gov/whitmer/news/press-releases/2022/09/09/whitmer-announces-plan-with-holtec-to-reopen-palisades-plant, accessed 1 August 2023.

784 - Sheri McWhirter, "Palisades Nuclear Plant Gets $150 Million in Michigan Budget", *MLive*, 5 July 2023, see https://www.mlive.com/public-interest/2023/07/palisades-nuclear-plant-gets-150-million-in-michigan-budget.html; and Governor Gretchen Whitmer, "Gov. Whitmer Signs 'Make it in Michigan' Budget", Office of the Governor, State of Michigan, Press Release, 31 July 2023, see https://www.michigan.gov/whitmer/news/press-releases/2023/07/31/whitmer-signs-make-it-in-michigan-budget, both accessed 14 August 2023.

785 - David Eggert, "Michigan dangles $150M toward restarting nuclear plant, but what else would it take?", *Crain's Detroit*, 7 August 2023, see https://www.crainsdetroit.com/energy/will-michigan-nuclear-plant-restart-state-money, accessed 10 August 2023.

boiled down to the uncompetitive costs of the long-term PPA under which Entergy had operated Palisades since it purchased the reactor from Consumers Energy (CE) in 2007, which had proven too expensive for CE and the Michigan Public Service Commission (MPSC) to justify.[786] By late 2016, CE and Entergy had reached an agreement to end the contract in 2018, which involved a US$172 million lump-sum payment to Entergy. The MPSC was not willing to have CE customers pay the full amount to end the contract early, and only approved the utility to recover US$136.6 million, despite an estimated US$344 million in savings that CE ratepayers would realize by ending the PPA four years early.[787] As a result, Entergy and CE decided to drop the matter, and, in September 2017, Entergy announced its plan to retire Palisades when the PPA expired on 31 May 2022.[788] State and local officials effectively had nearly five years notice of Palisades' closure, but only stepped in at the last minute when DOE began implementing the CNC program. If the effort succeeds, Michigan ratepayers may end up being forced to cover the costs of a long-term contract with an uncompetitive, out-of-market price for Palisades' electricity—the very situation that led to the decision to retire the reactor to begin with.

The Diablo Canyon Case

As described above, the effort to extend the operation of the Diablo Canyon-1 and -2 reactors—beyond 2024 and 2025 respectively—in California is similarly fraught. In 2016, PG&E entered into a settlement with four environmental organizations and two labor unions. Under the agreement, PG&E would withdraw its license renewal application at NRC, close the reactors when their operating licenses expire, make investments in renewables and energy efficiency to ensure it meets California's renewable energy and emissions goals, provide salary bonuses, training, and job opportunities for Diablo Canyon workers, and make stable property tax payments to local municipalities through 2025.[789] The California Public Utilities Commission (CPUC) approved the proposal in 2018,[790] after the California Legislature enacted a law expressly giving it the authority to implement the additional payments to workers and local communities and requiring the CPUC to ensure that Diablo Canyon's retirement would not result in increases in greenhouse gas emissions.

In subsequent proceedings since 2019, the CPUC issued orders to PG&E and all other utilities in the state to procure a total of 17.7 GW of renewable energy and storage capacity by 2026; in addition, counting deployment of renewables and storage under separate state legislation, total renewable energy and storage capacity additions would total 22 GW through 2026, the

786 - *WNN*, "Palisades to operate to 2022", *World Nuclear News*, 29 September 2017, see https://www.world-nuclear-news.org/C-Palisades-to-operate-to-2022-2909177.html, accessed 7 August 2023.

787 - Entergy, "Palisades Power Purchase Agreement to End Early", Press Release, 8 December 2016, see https://www.entergynewsroom.com/news/palisades-power-purchase-agreement-end-early/; and MPSC, "MPSC cuts to $142 million amount Consumers Energy can use to buy out its Palisades power contract", Press Release, Michigan Public Service Commission, 22 September 2017, see https://mi-psc.force.com/sfc/servlet.shepherd/version/download/068t0000001UWjEAAW; both accessed 14 August 2023.

788 - Entergy, "Entergy to Continue Operating Palisades Power Plant Until Spring 2022", Press Release, 28 September 2017, see https://www.entergynewsroom.com/news/entergy-continue-operating-palisades-power-plant-until-spring-2022/, accessed 14 August 2023.

789 - PG&E, "PG&E, labor and environmental groups file Diablo Canyon Joint Proposal with the CPUC", Press Release, 11 August 2016, see https://www.pge.com/en_US/safety/how-the-system-works/diablo-canyon-power-plant/news-and-articles/pge-labor-and-environmental-groups-file-diablo-canyon-joint-proposal-with-the-cpuc.page, accessed 14 August 2023.

790 - Public Utilities Commission of the State of California, "Decision 18-01-022—Decision Approving Retirement of Diablo Canyon Nuclear Power Plant", ALJ/PVA/jt2/lil, ruled 11 January 2018, issued 16 January 2018, see https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M205/K423/205423920.PDF, accessed 14 August 2023.

vast majority of which by the time Diablo Canyon-1 is to close in November 2024.[791] The CPUC has affirmed publicly that its system planning proceedings and procurement orders have been directed at assuring grid reliability and emissions reductions through the retirements of Diablo Canyon and several fossil fuel power plants.[792]

Driven by California's seasonal electricity reliability challenges,[793] Governor Gavin Newsom reversed course in early 2022, with a proposal to consider extending Diablo Canyon's operations beyond 2024 and 2025. The governor's proposal prompted DOE to amend in June 2022[794] the Civil Nuclear Credit program guidance it had issued only in April 2022,[795] under which Diablo Canyon likely would not have been eligible. To further accommodate the state's policymaking process, DOE twice extended the deadline for PG&E to apply: first, from 19 May to 5 July 2022 and then again to 6 September 2022.[796]

On 1 September 2022, the California legislature passed a bill proposed by Governor Gavin Newsom to extend Diablo Canyon's operations and make up to US$1.4 billion in loans available to PG&E to pursue 5-year extensions of the reactors' federal operating licenses, as well as deferred maintenance and other expenditures. The state funding is contingent on both Diablo Canyon's eligibility for Civil Nuclear Credits, as well as future determinations by the California Public Utilities Commission on the prudency of Diablo Canyon's cost to consumers and whether the reactors are needed to ensure transmission system reliability.[797]

The decision may delay the most deliberate and planned nuclear power-plant retirement in the U.S.

In July 2023, Environmental Working Group (EWG) published a report based on expert testimony provided to the California Public Utilities Commission (CPUC) by The Utility Reform Network (TURN). The report concludes that PG&E's plan to seek a license extension for the full 20 years (instead of the five years California requested) would end up costing

791 - NIRS et al., "For Immediate Release:170+ Organizations Sign Letter Opposing Subsidies to Delay Closure of Diablo Canyon Power Plant · NIRS", Nuclear Information and Resource Service, 22 June 2022, see https://www.nirs.org/press/for-immediate-release170-organizations-sign-letter-opposing-subsidies-to-delay-closure-of-diablo-canyon-power-plant/, accessed 22 September 2023.

792 - CPUC, "CPUC Orders Historic Clean Energy Procurement To Ensure Electric Grid Reliability and Meet Climate Goals", Press Release, California Public Utilities Commission, 24 June 2021, see https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-orders-clean-energy-procurement-to-ensure-electric-grid-reliability; and Peter Skala, "Letter to the Editor: CPUC responds to commentary on Diablo Canyon", CPUC, published in *Capitol Weekly*, 15 April 2022, see https://capitolweekly.net/letter-to-the-editor-cpuc-responds-to-inaccurate-commentary/, both accessed 4 September 2022.

793 - Anne C. Mulkern, "California Faces Summer Blackouts from Climate Extremes", *E&E News*, 23 May 2022, see https://www.scientificamerican.com/article/california-faces-summer-blackouts-from-climate-extremes/, accessed 4 September 2022.

794 - U.S. DOE, "Proposed Guidance Amendment for the Civil Nuclear Credit Program", U.S. Department of Energy, 17 June 2022, see https://www.energy.gov/sites/default/files/2022-06/Proposed%20CNC%20Guidance%20Amendment%206.17.2022_0.pdf, accessed 2 September 2022.

795 - U.S. DOE, "Notice of Availability of Guidance for the First Award Period of the Civil Nuclear Credit Program", Federal Register, 25 April 2022, see https://www.federalregister.gov/documents/2022/04/25/2022-08773/notice-of-availability-of-guidance-for-the-first-award-period-of-the-civil-nuclear-credit-program, accessed 2 September 2022.

796 - Office of Nuclear Energy, "U.S. Department of Energy Extends Application Deadline for $6 Billion Civil Nuclear Credit Program", Department of Energy, U.S. Government, 18 May 2022, see https://www.energy.gov/ne/articles/us-department-energy-extends-application-deadline-6-billion-civil-nuclear-credit; and Office of Nuclear Energy, "DOE to Revise Eligibility for Civil Nuclear Credit Program and Extend Submission Deadline", Department of Energy, U.S. Government, 30 June 2022, see https://www.energy.gov/ne/articles/doe-revise-eligibility-civil-nuclear-credit-program-and-extend-submission-deadline, both accessed September 2022.

797 - California Senate, "California Senate Bill 846—Diablo Canyon Powerplant: Extension of Operations", filed 2 September 2022, see https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB846, accessed 7 September 2022.

ratepayers "more than $20 billion to nearly $45 billion from 2023 through 2045 – or more", based on the range of projected operating costs provided by PG&E and TURN. [798]

The CPUC, meanwhile, affirmed and expanded its June 2021 order to all utilities and load-serving entities (LSEs) to procure significant amounts of renewable and storage capacity in preparation for the retirements of Diablo Canyon and several fossil fuel-fired power plants in the coming years. In the February 2023 decision, the CPUC confirmed that, while utilities were behind in procuring about 20 percent of the targeted capacity through 2023, only about one-third of that delayed capacity involved projects that are likely to be canceled, the rest being delayed but likely to be brought online.[799] The CPUC did update its demand forecasts based on the rate of temperature increases, and ordered utilities to procure an additional 4 GW of renewables and storage, increasing the total of new capacity under the order to 15.5 GW through 2028. The CPUC also rejected proposals from PG&E and Southern California Edison (SCE) to curtail some procurements due to the planned extension of Diablo Canyon, reaffirming its 2021 order that directs procurements toward the goal of assuring grid reliability when the reactors are to retire in 2024 and 2025. Through a separate proceeding this year, the CPUC is evaluating the cost-effectiveness of extending Diablo Canyon's operations for five years, per the directives of SB846.[800]

Beyond Diablo Canyon and Palisades, no further retirements have been announced. However, a number of reactors are approaching the expiration of their 60-year operating licenses, beginning in 2029 with Nine Mile Point-1, Ginna, and Dresden-2. All are owned by Constellation, but as of July 2023, the company has only announced its intent to submit an application to extend the license of Dresden-2 and -3 to 80 years.[801] In 2021, prior to the Constellation spin-off, Exelon received an exemption from the NRC's timely renewal regulation, in order to submit subsequent license renewal applications for Nine Mile Point-1[802] and Ginna[803] less than five years before their current licenses expire. Nuclear generators will likely weigh the costs and risks of further investments in the continued operation of their oldest and smallest reactors with the likelihood of longer-term subsidies and other business models emerging in the utility sector, such as hydrogen production.

798 - Grant Smith and Anthony Lacey, "Outrageous costs, deadly dangers: The real risks of keeping Diablo Canyon open", Environmental Working Group, 25 July 2023, see https://www.ewg.org/research/outrageous-costs-deadly-dangers-real-risks-keeping-diablo-canyon-open, accessed 7 August 2023.

799 - California Public Utilities Commission, "Rulemaking Docket 20-05-003: Decision Ordering Supplemental Mid-Term Reliability Procurement (2026-2027) And Transmitting Electric Resource Portfolios To California Independent System Operator For 2023-2024 Transmission Planning Process", R.20-05-003 ALJ/JF2/jnf, ruled 23 February 2023, issued 28 February 2023, see https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M502/K956/502956567.PDF, accessed 7 August 2023.

800 - California Energy Commission, "Diablo Canyon", 2023, see https://www.energy.ca.gov/data-reports/california-energy-planning-library/reliability/diablo-canyon, Legislative Counsel Bureau of the State of California, "Senate Bill No. 846—Chapter 239", filed with Secretary of State, 2 September 2022, see https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB846; both accessed 19 August 2023.

801 - Constellation, "Notice of Intent to Pursue Subsequent License Renewal Applications", RS-22-121, 10 CFR 54, submitted to U.S. Nuclear Regulatory Commission, 9 November 2022, see https://www.nrc.gov/docs/ML2231/ML22313A073.pdf, accessed 14 August 2023.

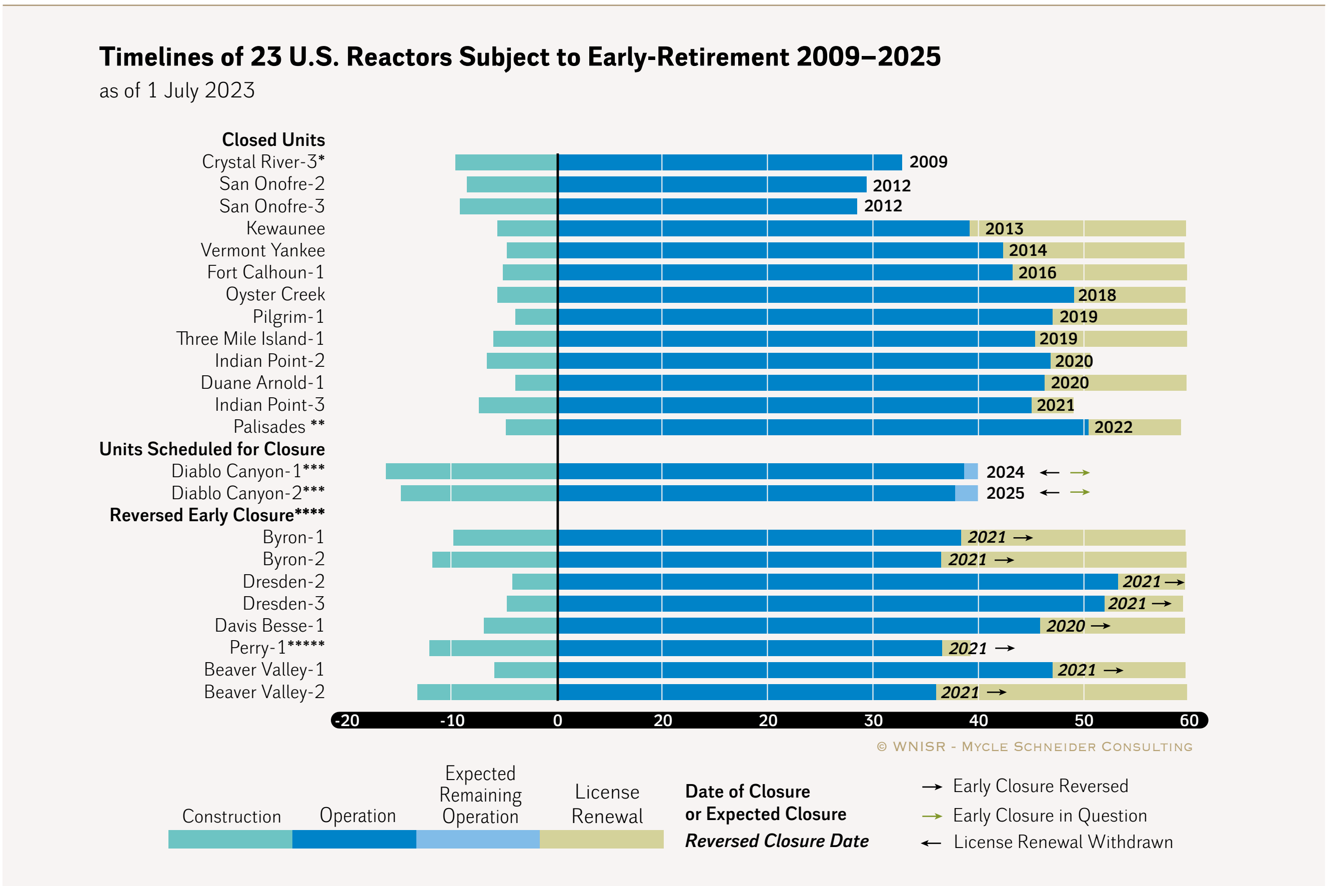
802 - U.S. NRC, "Exelon Generation Company, LLC; Nine Mile Point Nuclear Station, Unit 1", Docket No. 50–220; NRC–2021–0082, Federal Register, Vol. 86, No. 73, United States Nuclear Regulatory Commission, 19 April 2021, see https://www.federalregister.gov/documents/2021/04/19/2021-07975/exelon-generation-company-llc-nine-mile-point-nuclear-station-unit-1, accessed 7 August 2023.

803 - U.S. NRC, "Exelon Generation Company LLC, R.E. Ginna Nuclear Power Plant", Docket No. 50–244; NRC–2021–0075, Federal Register, Vol. 86, No. 74, 20 April 2021, U.S. Nuclear Regulatory Commission, see https://www.federalregister.gov/documents/2021/04/20/2021-08061/exelon-generation-company-llc-re-ginna-nuclear-power-plant, accessed 7 August 2023.

Securing Subsidies to Prevent Closures

As WNISR has reported in recent years, utilities have been lobbying for state legislation and contracts that would provide significant financial support for the operation of their uneconomic reactors since 2014 (see WNISR2018 Annex 4). A total of 23 reactors were scheduled for early retirement between 2009 and 2025, of which 13 have now been closed, eight had their closure delayed following subsidy programs, and two at Diablo Canyon remain in question (see Figure 52).

Figure 52 · Timelines of 23 Reactors Subject to Early Retirement in the United States



Sources: Various, compiled by WNISR, 2023

Notes:

* Crystal River: No production after 2009 (WNISR considers it closed as of this date). Official closure announced in 2013. Renewal application submitted in 2008, withdrawn in 2013. See U.S. NRC, "Crystal River – License Renewal Application", Updated 9 December 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/crystal-river.html, accessed 8 September 2020.

** Possible restart from early closure

*** Possible deferral of closure until 2029 and 2030. The Diablo Canyon-1 & -2 license renewal application was withdrawn in March 2018. However, on 31 October 2022, Pacific Gas and Electric sent a "Request to Resume Review of the Diablo Canyon Power Plant License Renewal Application or, Alternatively, for an Exemption from 10 CFR 2.109(b), Concerning a Timely Renewal Application". The NRC granted the exemption in March 2023, allowing for continued operation beyond current license while it reviews the new one, provided it is submitted by the end of 2023.

**** Early closure reversed following access to new subsidies. For Braidwood-1 & -2, and Byron-1 & -2, the enacted legislation extends the subsidies to 2027.

***** License Renewal Application cancelled in 2018. In 2020, Energy Harbor announced its intention to submit a new license renewal application, see Energy Harbor, "Notice of Intent to Submit License Renewal Application", 13 May 2020, see https://www.nrc.gov/docs/ML2013/ML20134H987.pdf, accessed 8 September 2022.

The application was submitted to the NRC on 3 July 2023, see Energy Harbor, "License Renewal Application for the Perry Nuclear Power Plant", Docket No. 50-440, License No. NPF-58, filed with U.S. NRC, 3 July 2023 see https://www.nrc.gov/docs/ML2318/ML23184A081.pdf, accessed 16 August 2023.

During the past few years, utilities have had less success in their ongoing efforts to secure state financial support for operating nuclear plants. As of July 2023, 18 reactors in the U.S. were receiving or are eligible for subsidies as a result of state legislation such as Zero Emission Credits (ZEC) or equivalent: Nine Mile Point-1 and -2, FitzPatrick, and Ginna in New York; Braidwood-1 and -2, Byron-1 and -2, Clinton, Dresden-2 and -3, and Quad Cities-1 and -2 in Illinois; Salem-1 and -2 and Hope Creek in New Jersey; and Millstone-2 and -3 in Connecticut.

ZEC subsidies in Ohio for Davis Besse and Perry were rescinded in 2021[804] before any of the funds had been disbursed. As a result of the federal corruption investigation into FirstEnergy's contributions of US$61 million to state legislators and political action committees to pass House Bill 6 (HB6) in 2019, the legislature repealed the nuclear subsidies in the bill (see previous WNISR editions).

The Inflation Reduction Act contains seven potential sources of funding and financing for existing and new reactors:[805]

- **Zero-Emission Nuclear Power Production Credit:** Production tax credits for existing reactors, available for nine years (2024 through 2032). All existing reactors are eligible. If a reactor owner meets prevailing wage and union apprenticeship requirements, they may claim as much as US$15/MWh in tax credits.[806] If not, the credits are worth a maximum of US$3/MWh. If the annual sales revenue of the reactor is greater than US$25/MWh, the value of the credits that can be claimed is reduced, phasing out at US$0 when a reactor's annual revenue reaches US$43.75/MWh. Other state or federal ZEC payments must be counted as sales revenue, unless those programs specify that their credits would be reduced in the amount of these federal credits.
- **Energy Infrastructure Reinvestment Financing:** A US$250 billion loan guarantee program for owners of existing energy infrastructure to finance projects that will "avoid, reduce, utilize, or sequester air pollutants or anthropogenic emissions of greenhouse gases." Existing reactors would likely be eligible for these loan guarantees, particularly for license renewals and/or major capital projects necessary to continue operating, such as steam generator replacements.
- **Tax Credits for new generation sources:**
  - **Clean Electricity Production Credit:** Production tax credits for new electricity sources, available for 10 years after the facility begins operation. New reactors would be eligible. Similar to the Nuclear Production Credit, the credit is worth US$15/MWh if the owner meets prevailing wage and union apprenticeship requirements, and only US$3/MWh otherwise. Facilities sited in "energy communities"[807] receive a 10 percent

804 - Jeremy Pelzer, "Gov. Mike DeWine signs repeal of nuclear bailout, other parts of scandal-tainted House Bill 6", *Cleveland.com*, 31 March 2021, see https://www.cleveland.com/open/2021/03/gov-mike-dewine-signs-repeal-of-nuclear-bailout-other-parts-of-scandal-tainted-house-bill-6.html, accessed 4 September 2022.

805 - The White House, "Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action", Version 2, U.S. Government, January 2023, see https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf; and IRS, "Request for Comments on Certain Energy Generation Incentives", Notice 2022-49, Internal Revenue Service, 5 October 2022, see https://www.irs.gov/pub/irs-drop/n-22-49.pdf; both accessed 15 August 2023.

806 - This provision is a modified version of legislation introduced in 2021, Zero-Emission Nuclear Power Production Credit Act of 2021 (S. 2291), on which WNISR reported previously.

807 - Defined as communities with high levels of unemployment where there are brownfield industrial sites or historical dependence on fossil fuel extraction, production, or generation.

bonus to the credit. An additional 10 percent bonus is available for facilities that meet domestic content requirements.

- **Clean Electricity Investment Credit:** Investment tax credits for new electricity sources. Facilities cannot claim both the production credit and the investment credit. Similar to the production credit, the investment credit can be claimed on 30 percent of the eligible investment amount for the facility if the owner meets prevailing wage and union apprenticeship requirements, but only 6 percent if it does not. Facilities sited in "energy communities" receive a 10 percent bonus to the credit. An additional 10 percent bonus is available for facilities that meet domestic content requirements.

→ **Loan Guarantees for New Clean Energy Sources:** Authorizes an additional US$40 billion for loan guarantees under DOE's existing program, for which new reactors would be eligible.

→ **Procurement of High-Assay Low-Enriched Uranium (HALEU):** Authorizes a total of US$700 million toward assuring the availability of HALEU for new commercial, reactors research, development, and demonstration (RD&D) projects, and commercial use. US$100 million is allocated for development and certification of transportation canisters. US$500 million is allocated for procurement of HALEU for a commercial reactor development consortium. US$100 million is to assure availability of HALEU for RD&D and commercial use.

→ **Hydrogen Production Tax Credit:** The IRA creates a new tax credit for the production of hydrogen. Producers that emit zero emissions and sell the hydrogen for US$1/kg or less are eligible for a tax credit of US$3/kg. Nuclear power stations that produce hydrogen through electrolysis at established efficiency rates of 1 kg per 41.5 to 52.5 kWh of electricity[808] could claim tax credits equivalent to an electricity subsidy of US$57–72/MWh.

It is not clear yet how the Nuclear and Hydrogen Production Tax Credits (PTCs) will interact with state nuclear subsidies. This is both because the IRS has not published final regulations on the tax credit programs, and because most of the states have not weighed in yet, either. The IRA provides for state subsidies to be defrayed by the Nuclear PTC, if the state subsidy program requires that nuclear generators reduce or refund ratepayers the value of the federal tax credits they receive. But it does not specify how the PTC value will be affected by state subsidies. For instance, New York's ZEC prices may be high enough in some years that the Nuclear PTC for those reactors should reduce to US$0/MWh. It would be inequitable for nuclear reactors in New York to be able to claim the full PTC, plus take home the additional ZEC price, while a nuclear generator in Ohio, with no state subsidy, may only be able to claim the PTC at a reduced value because its market revenue was not low enough. At the same time, New York has not stated if or how it would require Constellation to refund ZECs with PTC revenues.

Previous editions of WNISR have reported on conflicts in recent years over the impact of nuclear subsidies on wholesale electricity markets and proposals to adopt rules governing how state subsidies for incumbent nuclear power plants are rationalized in the competitive pricing auctions. Since state-level subsidies for merchant nuclear reactors were first implemented in 2016, regional wholesale markets (labeled alternately regional transmission organizations or independent system operators, RTOs or ISOs) and the Federal Energy Regulatory

808 - Loz Blain, "Record-breaking hydrogen electrolyzer claims 95% efficiency", *New Atlas*, 16 March 2022, see https://newatlas.com/energy/hysata-efficient-hydrogen-electrolysis/, accessed 7 August 2023.

Commission (FERC), which oversees them, have tried to balance the competing interests of different industry segments—principally, the coal, gas, and nuclear industries. These conflicts have subsided under the Biden administration and the closer alignment between FERC and state policies and programs to reduce power sector emissions and expand renewable energy.

Some state-driven subsidies may decline in importance to the nuclear industry while IRA programs like the Nuclear PTC are still available. For instance, efforts to secure ZEC legislation stalled in Pennsylvania in 2018, when the then-Governor announced his plan to join the Regional Greenhouse Gas Initiative (RGGI). The decision reportedly led Energy Harbor to reverse the decision to close Beaver Valley-1 and -2. However, the Nuclear PTC and Hydrogen PTC now offer subsidies to merchant nuclear generators in the RGGI states that may greatly exceed the market price bonus they receive through RGGI. Analysis in October 2019 reported that a carbon price of US$3 to US$5 per ton would be enough to keep nuclear plants in Pennsylvania economically viable for the foreseeable future.[809] That might translate to a market price bonus for nuclear and renewable generation of only US$1.5–5/MWh[810]—significantly less than the Nuclear PTC of up to US$15/MWh.

Prior to enactment of the IIJA and IRA, after Illinois enacted a second nuclear bailout program covering six more reactors, Exelon announced that it would not close any reactors in the state for at least six more years. A bill Illinois enacted in September 2021 authorized subsidies worth a total of US$694 million over five years for Braidwood-1 and -2, Byron-1 and -2, and Dresden-2 and -3[811]—more than a state-commissioned study concluded was necessary to guarantee the profitability of Exelon's then-unsubsidized Illinois reactors,[812] but far less than the subsidies for Clinton and Quad Cities-1 and -2 which the state enacted in 2016. Exelon had announced its intention to close Byron and Dresden in 2021 and threatened to consider closing Braidwood and LaSalle "in the event policy changes are not enacted".[813] Following enactment of the 2021 subsidy law, Exelon committed to keeping all of its Illinois reactors operational through May 2027, the period in which the subsidies are provided.

Mergers, Acquisitions, and Restructuring

In addition to the trends of closures and subsidies among existing reactors, there is a trend of corporate restructuring in the merchant nuclear sector over the past three years. The subsidies and financing available through the IRA have also begun to influence this trend, evidenced by mergers and acquisitions announced in 2023.

809 - Resources for the Future, "Options for Issuing Emissions Allowances in a Pennsylvania Carbon Pricing Policy", 21 October 2019, see https://www.rff.org/publications/issue-briefs/options-issuing-emissions-allowances-pennsylvania-carbon-pricing-policy/, accessed 6 July 2020.

810 - Kathryne Cleary and Karen Palmer, "Carbon Pricing 201: Pricing Carbon in the Electricity Sector", Resources for the Future, 20 August 2020, see https://www.rff.org/publications/explainers/carbon-pricing-201-pricing-carbon-electricity-sector/, accessed 7 August 2023.

811 - Catherine Clifford, "Why Illinois paid $694 million to keep nuclear plants open", *CNBC*, 20 November 2021, see https://www.cnbc.com/2021/11/20/illinois-nuclear-power-subsidy-of-694-million-imperfect-compromise.html, accessed 4 September 2022.

812 - Divita Bhandari, Max Chang et al., "Financial Audit of Exelon's Illinois Nuclear Power Plants", Synapse Energy Economics, 14 April 2021, see https://www.synapse-energy.com/financial-audit-exelons-illinois-nuclear-power-plants-0, accessed 21 September 2023.

813 - Ibidem.

In March 2023, Vistra announced that it reached a deal to acquire Energy Harbor for US$3.43 billion.[814] If approved, the deal would culminate the 2020 separation of Energy Harbor—and its 8 GW of merchant nuclear and coal generation—from FirstEnergy that had filed for bankruptcy protection,[815] while making Vistra a much larger player in the nuclear industry with six reactors totaling 6.4 GW of capacity.[816] The deal would also significantly increase Vistra's market share in the largest wholesale electricity market, PJM Interconnection. Some stakeholders have expressed concerns that it would give Vistra too much market power.[817]

In June 2023, Constellation announced that it will acquire NRG Energy's 44 percent controlling interest in the South Texas Project-1 and -2 reactors.[818] The deal would expand Constellation's holdings to more than 20 GW of nuclear capacity through its ownership shares in 25 reactors, while marking the exit of NRG from the nuclear industry.

The Vistra-Energy Harbor and Constellation-South Texas acquisitions may mark a further trend of ownership consolidation in the industry in the wake of the IRA, providing smaller merchant players in the industry an opportunity to divest large, non-core assets to larger industry players.

Prior to the IRA, a wave of restructuring set the stage for further consolidation, particularly in the merchant nuclear sector. Three utility holding companies that controlled approximately one-third of operating reactors a decade ago have divested their nuclear power plants, including FirstEnergy's aforementioned spin-off of its generation assets to Energy Harbor. Since 2014, Entergy has closed or sold off all six merchant reactors it acquired from their former utility owners between 1999 and 2007.[819] With the closure and sale of Palisades to Holtec for decommissioning, it has completed its exit from the merchant nuclear generation business. It still owns and operates five reactors through its regulated utility subsidiaries in Arkansas, Louisiana, and Mississippi.[820]

In February 2022, Exelon, by far the largest nuclear generator in the U.S., completed the spin-off of Constellation Energy Corp., with its holdings in 23 reactors and other merchant

814 - Vistra Corp, "Vistra to Create «Vistra Vision,» a Leading Zero-Carbon Generation and Retail Platform, Through the Acquisition of Energy Harbor", Press Release, 6 March 2023, see https://investor.vistracorp.com/2023-03-06-Vistra-to-Create-Vistra-Vision,-a-Leading-Zero-Carbon-Generation-and-Retail-Platform,-Through-the-Acquisition-of-Energy-Harbor; and Stephen Singer, "Vistra moves more deeply into nuclear power with planned $3.43B acquisition of Energy Harbor", *Utility Dive*, 7 March 2023, see https://www.utilitydive.com/news/vistra-energy-harbor-acquisition-nuclear-power/644276/, both accessed 15 August 2023.

815 - Jeremy Pelzer, "FirstEnergy Solutions emerges from bankruptcy, becomes Energy Harbor", *Cleveland.com*, 27 February 2020, see https://www.cleveland.com/open/2020/02/firstenergy-solutions-emerges-from-bankruptcy-becomes-energy-harbor.html, accessed 4 September 2022.

816 - Vistra owns the Comanche Peak-1 and -2 reactors in Texas, with 2,425 MW. Energy Harbor owns Beaver Valley-1 and -2 in Pennsylvania and Davis-Besse and Perry in Ohio, with 3,935 MW.

817 - Ethan Howland, "Vistra-Energy Harbor deal poses market power risks, say Ohio rate payer advocate, PJM market monitor", *Utility Dive*, 26 June 2023, see https://www.utilitydive.com/news/vistra-energy-harbor-nuclear-market-power-ferc-pjm/653876/, accessed 1 August 2023.

818 - Constellation, "Constellation to Acquire Ownership Stake in Texas Nuclear Plant from NRG Energy", Press Release, 1 June 2023, see https://www.constellationenergy.com/newsroom/2023/Constellation-to-Acquire-Ownership-Stake-in-Texas-Nuclear-Plant-from-NRG-Energy.html, accessed 15 August 2023.

819 - Entergy retired Indian Point-2 and -3 (2020 and 2021), Palisades (2022), Pilgrim (2018), and Vermont Yankee (2014), and sold FitzPatrick to Exelon (2016). It has also canceled a longstanding contract to manage the operations of Nebraska Public Power District's Cooper Nuclear Station (2022). Entergy has also transferred ownership of all of the reactors that it closed and their decommissioning funds to other firms that plan to decommission them: Northstar purchased Vermont Yankee, and Holtec International purchased Indian Point, Palisades, and Pilgrim.

820 - Arkansas-1 and -2, Grand Gulf 1, River Bend 1, and Waterford 3. See U.S. NRC, "List of Power Reactor Units", Updated 28 February 2023, see https://www.nrc.gov/reactors/operating/list-power-reactor-units.html, accessed 15 August 2023.

generation and power marketing ventures. In 2021, as the spin-off was being executed, Exelon also completed the acquisition of EDF's 50 percent stake in the corporations' joint venture Constellation Energy Nuclear Group, which owned five reactors. Following the spin-off, Constellation CEO Joe Dominguez stated that the corporation's growth strategy includes acquiring more merchant reactors "from other companies looking to exit the competitive power business."[821]

In 2020, Public Service Enterprise Group (PSEG) announced that it would divest its generation assets except its nuclear holdings,[822] which include interests in four reactors it co-owns with Constellation, as well as the Hope Creek reactor in New Jersey.[823] Soon after enactment of the IRA, analysts speculated that PSEG may strike a deal to transfer its ownership of the reactors to Constellation and fully exit the merchant generation business.[824] PSEG has also repurposed a site adjacent to its Salem-1 and -2 and Hope Creek reactors for which it received an early site permit in 2016[825] for an unspecified small modular reactor project. The site is now being developed to serve as a logistics facility for construction of offshore wind installations.[826]

The trend signals that utility holding companies believe regulated distribution utility operations will be the primary profit centers of their businesses going forward, and that owning and operating nuclear reactors in wholesale power markets is no longer in the interests of their shareholders, even with billions of dollars in state and federal subsidies.

New Business Models Emerging – Data Center, Crypto Mining, Hydrogen

Two trends have become evident, which suggest the U.S. industry may pursue more diversified business strategies through off-grid and value-added energy products and services:

- co-location of large data centers and/or cryptocurrency mining facilities on or adjacent to reactor sites, with contracts to provide direct power off-take; and
- production of hydrogen at reactor sites powered by off-take of electricity generation, possibly connected to regional hydrogen transmission and distribution infrastructure and/or cogeneration applications.

821 - Katherine Blunt, "This New Company Is Betting Big on Nuclear Power in America", *The Wall Street Journal*, 2 February 2022, see https://www.wsj.com/articles/this-new-company-is-betting-big-on-nuclear-power-in-america-11643820916, accessed 7 September 2022.

822 - Robert Walton, "PSEG to sell almost 7 GW of fossil fuel generation, retain nuclear plants", *Utility Dive*, 3 August 2020, see https://www.utilitydive.com/news/pseg-to-sell-almost-7-gw-of-fossil-fuel-generation-retain-nuclear-plants/582743/, accessed 4 September 2022.

823 - PSEG, "PSEG Nuclear LLC—About Our Plants", Public Service Enterprise Group, 2023, see https://corporate.pseg.com/aboutpseg/companyinformation/thepsegfamilyofcompanies/psegnuclearllc, accessed 15 August 2023.

824 - Jessica Sondgeroth and Stephanie Cooke, "US Enacts 'Game-Changing' Nuclear Tax Credits", *Energy Intelligence Weekly*, 19 August 2022, see https://www.energyintel.com/00000182-b682-d1ec-a1ee-befff53d0001, accessed 4 September 2022.

825 - U.S. NRC, "Issued Early Site Permit - PSEG Site", United Stated Nuclear Regulatory Commission, 8 January 2021, see https://www.nrc.gov/reactors/new-reactors/esp/pseg.html, accessed 4 September 2022.

826 - Tom Johnson, "A site once earmarked for nuclear power will now assemble wind turbines", *NJ Spotlight News*, 15 September 2021, see https://www.njspotlightnews.org/2021/09/nj-wind-power-pseg-salem-county-nuclear-power-lease-turbines-port/, accessed 4 September 2022.

Each of these opportunities has the potential to result in allocating large amounts of nuclear generation capacity to off-grid applications.

Three nuclear generators have announced contracts to power data centers and/or crypto mines at five reactor sites, with power contracts totaling between 700 MW and 2.5 GW of generation, and a data center developer has announced plans to procure power from an adjacent nuclear power plant, pending construction of on-site SMRs:

- **Susquehanna-1 and -2:** in 2021, Talen Energy has signed a contract with TeraWulf to construct data center and crypto mining facilities at the Susquehanna Nuclear Power Plant in Pennsylvania through a joint venture named Nautilus Cryptomine.[827] The contract includes supplying 300 MW of power in Phases 1 and 2 of the project, with options to expand the operations for up to 1 GW of generation—approximately 40 percent of Susquehanna's rated capacity. TeraWulf reported in March 2023 that the first crypto-mining facilities—initially expected to operate in mid-2022—are operational.[828]
- **Millstone-2 and -3:** Dominion has signed an agreement with NE Edge LLC to construct a 1.5 million square-foot data-center at the Millstone Nuclear Power Plant in Connecticut.[829] The amount of power consumption has not been reported, but it would be in the range of 225 MW to 450 MW at standard data center rates of 150–300 watts/square foot;[830] or as much as 600 MW at the higher end of 400 watts/square foot.[831]
- **Beaver Valley, Davis-Besse, Perry:** Energy Harbor has signed contracts with three firms—Standard Power, TAAL, and Lake Parime—to construct data centers at its three nuclear power plants. In 2022, Energy Harbor signed an MoU with Standard Power for 200–300 MW of power for a crypto and data center to be built at the Beaver Valley site, with options to expand up to 900 MW (approximately 50 percent of the plant's rated capacity).[832] The other Standard Power and TAAL/Parime contracts allocated up to 60 MW

827 - Talen Energy, "Talen Energy Corporation Announces Zero-Carbon Bitcoin Mining Joint Venture with TeraWulf Inc.", Press Release, 3 August 2021, see https://talenenergy.investorroom.com/2021-08-03-Talen-Energy-Corporation-Announces-Zero-Carbon-Bitcoin-Mining-Joint-Venture-with-TeraWulf-Inc; and Dan Swinhoe, "Talen Energy to build 300MW nuclear-powered cryptomining facility and data center in US", Data Centre Dynamics, 12 July 2021, see https://www.datacenterdynamics.com/en/news/talen-energy-to-build-300mw-nuclear-powered-cryptomining-facility-and-data-center-in-us/, both accessed 15 August 2023.

828 - Kevin Clark, "Nuclear-powered bitcoin mining operations ramp up in Pennsylvania", *Power Engineering*, 20 March 2023, see https://www.power-eng.com/nuclear/nuclear-powered-bitcoin-mining-operations-ramp-up-in-pennsylvania/; and TeraWulf, "TeraWulf Announces Energization and Rapid Deployment of Mining Operations at the Nautilus Facility in Pennsylvania", Press Release, as published on BusinessWire, 6 March 2023, see https://www.businesswire.com/news/home/20230305005096/en/TeraWulf-Announces-Energizatio[%E2%80%A6]Mining-Operations-at-the-Nautilus-Facility-in-Pennsylvania; both accessed 15 August 2023.

829 - Brendan Crowley, "NE Edge Proposes 1.5M Square Foot Data Center at Millstone in Waterford", *CT Examiner*, 16 February 2023, see https://ctexaminer.com/2023/02/16/ne-edge-proposes-1-5m-square-foot-data-center-at-millstone/, accessed 1 August 2023.

830 - Josh Mahan, "Understanding Data Center Energy Consumption", C&C Technology Group, 8 June 2023, see https://cc-techgroup.com/data-center-energy-consumption/, accessed 7 August 2023.

831 - Grant Gross, "New Workloads, Cost Pressures Drive Up Data Center Power Densities", Data Center Knowledge, 18 April 2018, see https://www.datacenterknowledge.com/power-and-cooling/new-workloads-cost-pressures-drive-data-center-power-densities, accessed 7 August 2023.

832 - Dan Swinhoe, "Standard Power to build massive blockchain data center at Pennsylvania nuclear power station", Data Centre Dynamics, 9 May 2022, see https://www.datacenterdynamics.com/en/news/standard-power-to-build-massive-blockchain-data-center-at-pennsylvania-nuclear-power-station/, accessed 1 August 2023.

of generation for facilities to be located at one or both of Energy Harbor's Ohio reactors, Davis-Besse and Perry.[833]

- **Surry-1 and -2, plus SMRs:** Green Energy Partners (GEP) announced that it has purchased 641 acres next to Dominion's Surry Nuclear Power Plant in Virginia. GEP plans to build up to 30 data centers at the property, along with hydrogen production. It eventually intends to power the 1 GW operation with four to six SMRs and possibly integrate storage capacity but will purchase power from the Surry reactors until then, amounting to more than half of Surry nuclear power plant's rated capacity.[834]

Following execution of Constellation's spinoff from Exelon in 2022, CEO Joe Dominguez expressed interest in siting data centers at the company's nuclear power plants.[835] While the company has not reported signing any such agreements yet, a company statement from January 2022 claimed:

> Constellation is exploring growth opportunities that build on its core businesses, including acquiring nuclear plants or other clean energy assets, creating clean hydrogen using its nuclear fleet, growing sustainability products and services for business customers, and leveraging the generation fleet for colocation of data centers and other opportunities.[836]

The nuclear industry currently has less capacity targeting hydrogen production than data centers. However, there is great interest in hydrogen in the utility, fossil fuel, and nuclear industries, which see it as a sort of universal fuel substitute—while it is obviously an energy carrier not a source—that can help to preserve their core businesses and claim to be contributing to emissions reductions. To date, hydrogen production is still almost exclusively created from fossil fuels, most commonly and affordably through steam reformation of methane, which entails significant greenhouse gas emissions both from methane leakage and generation of carbon dioxide as a byproduct.

DOE has an extensive hydrogen Research & Development (R&D) program, through which it hopes to identify technologies to produce it affordably, at a cost of around US$1/kg.[837] DOE launched a pilot program to test various production technologies at nuclear power plants, and has awarded cost-sharing grants for pilot projects at four sites:

833 - Dan Swinhoe, "TAAL & Lake Parime to deploy cryptomine at Ohio nuclear power station", Data Centre Dynamics, 12 July 2022, see https://www.datacenterdynamics.com/en/news/taal-lake-parime-to-delpoy-cryptomine-at-ohio-nuclear-power-station/; and Dan Swinhoe, "Energy Harbor Corp. & Standard Power sign partnership to power Ohio crypto-mining facility with nuclear energy", Data Centre Dynamics, 19 July 2021, see https://www.datacenterdynamics.com/en/news/energy-harbor-corp-standard-power-sign-partnership-to-power-ohio-crypto-mining-facility-with-nuclear-energy-energy/, both accessed 7 August 2023.

834 - Green Energy Partners, "Introducing the Nation's First Green Integrated Energy Center", Press Release, 12 April 2023, see https://water2.energy/wp-content/uploads/2023/04/GEP-Green-Integrated-Energy-Center-April2023.pdf, and Peter Judge, "Finally - a nuclear powered data center?", Data Centre Dynamics, 22 June 2023, see https://www.datacenterdynamics.com/en/analysis/finally-a-nuclear-powered-data-center/, accessed 15 August 2023.

835 - Dan Swinhoe, "Constellation Energy splits from Exelon, aims to colocate data centers at power plants", Data Centre Dynamics, 4 February 2022, see https://www.datacenterdynamics.com/en/news/constellation-energy-splits-from-exelon-aims-to-colocate-data-centers-at-power-plants/, accessed 1 August 2023.

836 - Constellation, "Constellation Shares Plan to Lead America's Transition to a Carbon-Free Future as it Prepares for Separation from Exelon", Press Release, January 2022, see https://www.constellationenergy.com/newsroom/2022/constellation-shares-plan-to-lead-americas-transition-to-a-carbon-free-future-as-it-prepares-for-separation-from-exelon.html, accessed 15 August 2023.

837 - U.S. DOE, "Hydrogen Program Plan", Department of Energy, U.S. Government, November 2020, see https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf; and U.S.DOE, "Hydrogen Shot", Department of Energy, U.S. Government, Undated, see https://www.energy.gov/eere/fuelcells/hydrogen-shot; both accessed 15 August 2023.

- Constellation's Nine Mile Point-1 and -2 in New York;[838]
- APS's Palo Verde-1, -2, and -3 in Arizona;[839]
- Energy Harbor's Davis-Besse in Ohio;[840] and
- Xcel's Prairie Island-1 and -2 in Minnesota.[841]

Constellation began operating a 1.25 MW hydrogen electrolyzer at the two-unit 1900-MW Nine Mile Point plant in early 2023 with a US$5.8 million cost-sharing grant from DOE.[842] Nine Mile Point has also been awarded US$12.5 million by the New York State Energy Research and Development Authority[843] to install a 10 MW hydrogen fuel cell on-site as a power generation demonstration.[844]

The company envisions producing hydrogen at its nuclear power plants for a wide range of applications, including power generation, transportation, and industrial production. CEO Joe Dominguez announced a US$900 million investment in large-scale hydrogen production at one of Constellation's Illinois reactor sites,[845] and indicated that the company may dedicate up to half of the generation capacity of some nuclear power plants to producing hydrogen.[846] In addition, Constellation issued a statement in May 2023 claiming to have demonstrated the feasibility of using hydrogen in natural gas plants, by successfully operating its 753 MW Hillabee power plant in Alabama on a 38-percent hydrogen mixture.[847]

838 - Exelon, "Exelon Generation Receives DOE Grant to Support Hydrogen Production Project at Nine Mile Point Nuclear Station", Press Release, 18 August 2021, see https://www.exeloncorp.com/leadership-and-governance/governance-overview, accessed 15 August 2023.

839 - U.S. DOE, "DOE Announces $20 Million to Produce Clean Hydrogen From Nuclear Power", Press Release, Department of Energy, U.S. Government, 7 October 2021, see https://www.energy.gov/articles/doe-announces-20-million-produce-clean-hydrogen-nuclear-power, accessed 15 August 2023.

840 - Tom Henry, "Toledo-area consortium likes chances of becoming 'hydrogen hub'", *The Blade*, 19 November 2022, see https://www.toledoblade.com/local/city/2022/11/18/regional-consortium-hydrogen-hub/stories/20221118012, accessed 7 August 2023.

841 - Xcel Energy, "Pioneering a bridge between nuclear and a hydrogen economy", Press Release, 15 July 2022, see https://stories.xcelenergy.com/ArticlePage/?id=Pioneering-a-bridge-between-nuclear-and-a-hydrogen-economy, accessed 15 August 2023.

842 - Michael Barnard, "Manufacturing Hydrogen For Cooling In New York's Nine Mile Point Nuclear Plant Makes Sense", *CleanTechnica*, 8 March 2023, see https://cleantechnica.com/2023/03/08/manufacturing-hydrogen-for-cooling-in-new-yorks-nine-mile-point-nuclear-plant-makes-sense/amp/; and Constellation, "Constellation Starts Production at Nation's First One Megawatt Demonstration Scale Nuclear-Powered Clean Hydrogen Facility", Press Release, 7 March 2023, see https://www.constellationenergy.com/newsroom/2023/Constellation-Starts-Production-at-Nations-First-One-Megawatt-Demonstration-Scale-Nuclear-Powered-Clean-Hydrogen-Facility.html; both accessed 15 August 2023.

843 - New York State, "Governor Hochul Announces $16.6 Million in Awards for Five Long Duration Energy Storage Projects", Press Release, 8 September 2022, see https://www.nyserda.ny.gov/About/Newsroom/2022-Announcements/2022-09-08-Governor-Hochul-Announces-Millions-in-Awards-for-Five-Energy-Storage-Projects, accessed 22 September 2023.

844 - Tim Knauss, "New York Nuclear Plant Could Lead Way in Hydrogen Power", *Syracuse.com*, as published on *Government Technology*, 29 September 2022, see https://www.govtech.com/products/new-york-nuclear-plant-could-lead-way-in-hydrogen-power, accessed 22 September 2023.

845 - Allison Good, "Constellation to build $900M green hydrogen production facility", S&P Global, 16 February 2023, see https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/constellation-to-build-900m-green-hydrogen-production-facility-74372628, accessed 1 August 2023.

846 - Lorraine Mirabella, "Baltimore-based Constellation Energy pursues 'hydrogen economy' to meet global climate goals", *The Baltimore Sun*, 21 October 2022, see https://www.baltimoresun.com/business/bs-bz-climate-hydrogen-economy-20221021-wqx4i5kn75f7lniwqhysttiyim-story.html, accessed 7 August 2023.

847 - Constellation, "Constellation Sets Industry Record for Blending Hydrogen with Natural Gas to Further Reduce Emissions", Press Release, 24 May 2023, see https://www.constellationenergy.com/newsroom/2023/Constellation-sets-industry-record-for-blending-hydrogen-with-natural-gas-to-further-reduce-emissions.html; and Morgan Evans, "Constellation Sets Record for Hydrogen, Natural Gas Blending at Hillabee Facility in Alabama", *Natural Gas Intelligence*, 25 May 2023, see https://www.naturalgasintel.com/constellation-sets-record-for-hydrogen-natural-gas-blending-at-hillabee-facility-in-alabama/; both accessed 15 August 2023.

The DOE's implementation of the IIJA's US$8 billion Regional Hydrogen Hub pilot program[848] has attracted wide interest across the industry. Per the legislation, the program must fund at least four projects, involving a range of technologies. The agency received close to 80 draft concepts in response to its initial solicitation in 2022 and selected 33 in December 2022 to submit detailed proposals by April 2023.[849] Of the projects selected to submit proposals, eight involve production of hydrogen at nuclear power plants. Award negotiations are scheduled to take place by the end of October 2023.

Beyond the utility industry's self-interest in utilizing hydrogen to prolong the profitability of its transmission and distribution networks, the Hydrogen PTC may provide the most powerful and potentially lucrative incentives for the nuclear industry, depending on how IRS implements it. As mentioned above, the US$3/kg value of the tax could translate into an electricity subsidy of US$56–72/MWh—nearly four to five times the maximum value of the Nuclear PTC and substantially greater than the average market price of electricity. Even if the industry's uptake as a whole is much more modest than Constellation envisions for itself, it could become a powerful incentive to divert significant amounts of nuclear generation to off-grid consumption. If the industry were to increase hydrogen production to 10 percent of its generation over the next decade, the Hydrogen PTC could yield US$4–5 billion per year.

Reactor Construction

« The Company provided eleven cost estimates (certification and ten revisions) prior to and during construction of the Project, and at least the first ten were materially inaccurate. »

Testimony on behalf of the Georgia Public Service Commission Public Interest Advocacy Staff, 22 June 2023[850]

The Vogtle Debacle

The only two commercial reactors in the U.S. that began construction after the 1970s—and have not been abandoned during construction—have now been completed: the AP-1000 reactors Vogtle-3 and -4, which began construction respectively in March and November 2013.[851] At construction start of Unit 3, the projected cost of the twin-unit project was around

848 - U.S. DOE, "DOE Establishes Bipartisan Infrastructure Law's $9.5 Billion Clean Hydrogen Initiatives", Press Release, U.S. Department of Energy, United States Government, 15 February 2022, see https://www.energy.gov/articles/doe-establishes-bipartisan-infrastructure-laws-95-billion-clean-hydrogen-initiatives, accessed 15 August 2023.

849 - Lucie Bioret, Yuqi Zhu and Alan Krupnick, "Hydrogen Hubs: Get to Know the Encouraged Applicants", Resources for the Future, 7 February 2023, see https://www.resources.org/common-resources/hydrogen-hubs-get-to-know-the-encouraged-applicants/; and Office of Clean Energy Demonstration, "Regional Clean Hydrogen Hubs Notifications", U.S. Department of Energy, U.S. Government, Undated, see https://www.energy.gov/oced/regional-clean-hydrogen-hubs-notifications; accessed 15 August 2023.

850 - Tom Newsome, Philip Hayet, Lane Kollen, "In the Matter Of: Georgia Power Company's Twenty-Eighth Semi-Annual Vogtle Construction Monitoring ('VCM') Report—Direct Testimony and Exhibits", on Behalf of the Georgia Public Service Commission Public Interest Advocacy Staff, Before the Georgia Public Service Commission, 22 June 2023, see https://services.psc.ga.gov/api/v1/External/Public/Get/Document/DownloadFile/204891/86214, accessed 26 August 2023.

851 - WNISR, "Construction Start on US Vogtle Unit 4", World Nuclear Industry Status Report, 25 November 2013, see https://www.worldnuclearreport.org/Construction-Start-on-US-Vogtle.html, accessed 20 July 2021.

US$14 billion, with construction expected to be complete in 2017 and 2018 respectively.[852] The reactors are located in Burke County, near Waynesboro, in the state of Georgia, in the southeastern U.S. and are owned by Southern Company (parent company of Plant Vogtle's controlling owner, Georgia Power).

In 2017, Southern Company delayed the projected fuel-loading schedule to November 2021 for Unit 3 and November 2022 for Unit 4, and those dates continued to slip. In 2023 alone, commercial operation of Vogtle-3 was pushed back several times. The unit went critical in March[853] and was connected to the grid on 1 April,[854] reached full power on 29 May,[855] and entered commercial operation on 31 July.[856]

A series of equipment problems took the reactor offline for nearly half of the time between first grid connection and commercial operation: the reactor automatically shut down on 10 April due to low coolant flow because of low voltage to the reactor coolant pumps,[857] and was offline for five days;[858] in May, a problem with the suction strainers on the main feed pumps[859] took two weeks to repair;[860] a hydrogen coolant leak in the main turbine[861] shut down the reactor for 36 days in June and July;[862] and a power supply problem in a reactor coolant pump took another five days to repair in July.[863] Southern Company was able to complete repairs in time to bring the reactor to full power and enter commercial operation by a milestone date of 31 July 2023.[864]

852 - WNISR, "Construction Start at Vogtle Reactor in the US", World Nuclear Industry Status Report, 16 March 2013, see https://www.worldnuclearreport.org/Construction-Start-at-Vogtle.html, accessed 7 September 2022.

853 - Georgia Power, "Vogtle Unit 3 reaches initial criticality", Press Release, 6 March 2023, see https://www.georgiapower.com/company/news-center/2023-articles/vogtle-unit-3-reaches-initial-criticality.html, accessed 15 August 2023.

854 - Georgia Power, "Vogtle 3 & 4 nuclear units take significant steps toward operations", Press Release, 1 April 2023, see https://www.georgiapower.com/company/news-center/2023-articles/vogtle-steps-toward-operations.html, accessed 15 August 2023.

855 - Georgia Power, "Vogtle Unit 3 reaches 100 percent energy output for the first time", Press Release, 29 May 2023, see https://www.georgiapower.com/company/news-center/2023-articles/vogtle-unit-3-reaches-100-percent-energy-output.html, accessed 15 August 2023.

856 - Georgia Power, "Vogtle Unit 3 goes into operation", Press Release, 31 July 2023, see https://www.georgiapower.com/company/news-center/2023-articles/vogtle-unit-3-goes-into-operation.html, accessed 15 August 2023.

857 - U.S. NRC, "Event Notification Report for April 11, 2023—NRC Event Number 56460", United States Nuclear Regulatory Commission, 11 April 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/event/2023/20230411en.html, accessed 9 August 2023.

858 - U.S. NRC, "Power Reactor Status Report for April 15, 2023", United States Nuclear Regulatory Commission, 15 May 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2023/20230415ps.html, accessed 9 August 2023.

859 - U.S. NRC, "Event Notification Report for May 03, 2023—NRC Event Number: 56497", United States Nuclear Regulatory Commission, 2 May 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/event/2023/20230503en.html, accessed 5 August 2023.

860 - U.S. NRC, "Power Reactor Status Report for May 16, 2023", United States Nuclear Regulatory Commission, 16 May 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2023/20230516ps.html, accessed 5 August 2023.

861 - Jeff Amy, "Georgia Power Says Vogtle Nuclear Reactor Delayed Another Month by Turbine Problem", *The Associated Press*, 16 June 2023, see https://apnews.com/article/georgia-power-vogtle-nuclear-power-plant-southern-a0ede9dd77842cf5c9b0c2a0a71de970, accessed 15 August 2023.

862 - U.S. NRC, "Power Reactor Status Report for July 06, 2023", United States Nuclear Regulatory Commission, Updated 15 August 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2023/20230706ps.html; and U.S. NRC, "Power Reactor Status Report for July 18, 2023", Updated 15 August 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2023/20230706ps.html; also Jeff Amy, "Georgia Power says Vogtle nuclear reactor delayed another month by turbine problem", *The Associated Press*, 16 June 2023, see https://apnews.com/article/georgia-power-vogtle-nuclear-power-plant-southern-a0ede9dd77842cf5c9b0c2a0a71de970, all accessed 19 August 2023.

863 - U.S. NRC, "Event Notification Report for July 24, 2023—NRC Event Number: 56632", United States Nuclear Regulatory Commission, 24 July 2023, see https://www.nrc.gov/reading-rm/doc-collections/event-status/event/2023/20230724en.html, accessed 5 August 2023.

864 - Southern Company, "Vogtle Unit 3 goes into operation", Press Release, 31 July 2023, see https://southerncompany.mediaroom.com/2023-07-31-Vogtle-Unit-3-goes-into-operation, accessed 16 August 2023.

On 20 July 2023, Southern Company notified NRC that it had completed construction of Unit 4 and submitted the 346 ITAACs final inspection reports.[865] NRC certified its acceptance of the reports on 28 July and authorized Southern Company to begin fuel loading and commence startup.[866] As of July 2023, Southern projects the reactor will enter service in late-2023 or early-2024.[867]

During the final years of construction, evidence has continued to emerge that reveals the enormous scale of the Vogtle project failure. While the project passed the necessary construction milestones, there were continual delays due to the emergence of significant problems. In 2021, Southern revealed that it had failed to document over 26,000 inspection records for correcting errors in electrical cable installations.[868] NRC issued violations for the errors in 2021, requiring additional oversight and many months for Southern to complete.[869] In granting approval for fuel loading in August 2022, NRC concluded that Southern Company had completed the ITAACs reports for Vogtle-3 to begin operation.[870] Then, during pre-operational testing of Unit 3, the company discovered vibrations in the cooling system due to inadequate installation of piping supports, forcing the reactor offline for several weeks, further delaying startup and increasing costs.[871]

Cost Escalation

Critics of the Vogtle project had long predicted that there would be delays and that costs would be much higher than anticipated.[872] Georgia Power's original 46.7 percent share of the project cost approved by the Georgia Public Service Commission (PSC) was US$6.1 billion

865 - Southern Nuclear, "Vogtle Electric Generating Plant Unit 4—Notification of Completion of All ITAAC", Docket No. 52-026, submitted to U.S. NRC, 20 July 2023, see https://www.nrc.gov/docs/ML2320/ML23201A266.pdf, accessed 16 August 2023.

866 - Office of Nuclear Reactor Regulation, "Finding That All Acceptance Criteria Are Met for the Vogtle Electric Generating Plant, Unit 4, Combined License", U.S. NRC, addressed to Southern Nuclear Operating Company, 28 July 2023, see https://www.nrc.gov/docs/ML2234/ML22348A094.pdf; and Georgia Power, "Vogtle Unit 4 has received the 103(g) finding from the Nuclear Regulatory Commission", Press Release, 28 July 2023, see https://www.georgiapower.com/company/news-center/2023-articles/vogtle-unit-4-has-received-the-103g-finding-from-the-nuclear-reg.html; both accessed 16 August 2023.

867 - Southern Company, "Vogtle Unit 3 goes into operation", Press Release, 31 July 2023, op. cit.

868 - Drew Kahn, "Monitors blame Georgia Power's lax oversight for Plant Vogtle delays", *Atlanta Journal-Constitution*, 19 July 2022, see https://www.ajc.com/news/monitors-blame-georgia-powers-lax-oversight-for-plant-vogtle-delays/BGRQWF65PFDMLB5QXKT7XYZLZQ/, accessed 1 September 2022.

869 - Jeff Amy, "Nuclear regulators uphold violations at Georgia reactors", *The Associated Press*, 19 November 2021, see https://www.statesboroherald.com/local/nuclear-regulators-uphold-violations-georgia-reactors/; and U.S. NRC, "Vogtle Electric Generating Plant, Unit 3 – Final Significance Determination of a Preliminary White Finding, a Preliminary Greater than Green Finding, Notice of Violation, and Assessment Follow-Up Letter, NRC Special Inspection Report 05200025/2021011", 17 November 2021, see https://www.nrc.gov/docs/ML2131/ML21312A412.pdf, both accessed September 2022.

870 - Office of Nuclear Reactor Regulations, "Finding that all Acceptance Criteria are met for the Vogtle Electric Generating Plant, Unit 3, Combined License", U.S. NRC, addressed to Southern Nuclear Operating Company, 3 August 2022, see https://www.nrc.gov/docs/ML2029/ML20290A284.pdf, accessed 5 September 2022.

871 - Abbie Bennett, "Georgia Power delays 1st new Vogtle unit in-service date to May or June", S&P Global, 16 February 2023, see https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/georgia-power-delays-1st-new-vogtle-unit-in-service-date-to-may-or-june-74372415; and Jeff Amy, "Georgia nuclear plant startup delayed due to vibrating pipe", *The Associated Press*, 12 January 2023, see https://apnews.com/article/business-georgia-power-co-dalton-southern-atlanta-e86bf4c3af41271c1bf2ececfc371be7, accessed 16 August 2023.

872 - For example, see NIRS,"MIT Nuke Study Uses Unsupportable Reactor Cost Estimates", Press Release, Nuclear Information and Resource Service, 16 September 2010, see https://www.commondreams.org/newswire/2010/09/16/mit-nuke-study-uses-unsupportable-reactor-cost-estimates, accessed 23 May 2018; and Travis Madsen, Johanna Neumann and Emily Rusch, "The High Cost of Nuclear Power—Why America Should Choose a Clean Energy Future Over New Nuclear Reactors", Maryland PIRG Foundation, March 2009, see https://www.nirs.org/wp-content/uploads/nukerelapse/calvert/highcostnpower_mdpirg.pdf, accessed 28 May 2019.

in 2009,[873] which corresponds to a cost of US$5,975/kW (gross), whereas the 2017—estimate of US$23 billion translated to a cost of US$10,300/kW. The revised 2018-estimate was in the range of US$28 billion.[874] As of June 2022, total project costs were reported to have increased to US$30.34 billion, or US$13,581/kW—2.3 times greater than the original approved cost estimate.[875] Those figures did not include US$3.68 billion Westinghouse's then-owner Toshiba refunded to the Vogtle owners in 2017.[876] As of Unit 3's entry into commercial operation, the co-owners' costs are over US$31 billion. Taking the settlement funds from Toshiba-Westinghouse into account, actual construction cost is ~US$35 billion, or US$15,766/kW and more than 2.5 times the original approved cost. These costs are nearly quadruple the Massachusetts Institute of Technology (MIT) 2009-assessment of the prospects for new nuclear power, which was based on overnight costs of $US\$_{2007}$4,000/kW.[877]

As WNISR2018 reported, in December 2017, the Georgia PSC, following the recommendation from Southern Company, decided to continue to support the project. The Georgia PSC has backed the Plant Vogtle project from the start, including awarding the generous Construction Work In Progress (CWIP), where interest payments on all construction costs incurred by Georgia Power are passed directly on to the customer. The Georgia Nuclear Energy Financing Act, signed into law in 2009, allows regulated utilities to recover from their customers the financing costs associated with the construction of nuclear generation projects—years before those projects are scheduled to begin producing benefits for ratepayers.

"As a result of further delays, customer subsidies have risen to US$926 per household"

As a result of the CWIP legislation, out of Georgia Power's original estimated US$6.1 billion Vogtle costs, US$1.7 billion is financing costs recoverable from the ratepayer. The utility began recovering these financing costs from its customers starting in 2011. For that first year, the rule translated to Georgia Power household electric bills' rising by an average of US$3.73 *per month*. Georgia Power estimated that this monthly charge would escalate so that by 2018, Georgia Power residential customers consuming 1,000 kWh per month would have seen their bill go up by US$10 per month due to Vogtle-3 and -4. As a result of increased costs of the project and approval by the Georgia PSC, ratepayers had already paid US$2 billion to Georgia Power as of November 2017.[878] In June 2021, Georgia PSC staff estimated that the average household customer of Georgia Power will have paid US$854 for Vogtle-3 and -4 construction before the

873 - Matt Kempner, "Georgia Power's Vogtle overruns could mean billions more in profits", *Atlanta Journal Constitution*, 9 July 2021, see https://www.ajc.com/news/business/nuclear-cost-overrun-could-mean-billions-in-extra-georgia-power-profit/YIA3T3YHZRHI5A7GCZHREIXCPE/, accessed 6 September 2022.

874 - Liam Denning, "Nuclear Power's Big Problem Isn't That It's Nuclear", *Bloomberg*, 27 September 2018, see https://www.bloomberg.com/opinion/articles/2018-09-27/nuclear-power-s-big-problem-isn-t-that-it-s-nuclear, accessed 28 May 2019.

875 - Jeff Amy, "Georgia cooperatives move to freeze nuclear costs at $8.1B", *Associated Press*, 18 June 2022, see https://apnews.com/article/georgia-power-co-atlanta-augusta-climate-and-environment-979a72d8e8626bce1341be0d69dba219, accessed 19 August 2023.

876 - Georgia Power, "Toshiba fulfills $3.68 billion parent guarantee obligation for Vogtle nuclear expansion", Press Release, as published on *PR Newswire*, 14 December 2017, see https://www.prnewswire.com/news-releases/toshiba-fulfills-368-billion-parent-guarantee-obligation-for-vogtle-nuclear-expansion-300571464.html, accessed 1 September 2022.

877 - MIT Energy Initiative, "The Future of Nuclear Power—2009 Update to the 2003 Report", Massachusetts Institute of Technology, 2009, see http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf, accessed 5 August 2019.

878 - Southern Environmental Law Center, "Groups Intervene in Vogtle Cost Proceedings—Georgians Should Not Bear Financial Burden of Georgia Power's Project Mismanagement", Press Release, as published on *PR Newswire*, 6 November 2017, see https://www.prnewswire.com/news-releases/groups-intervene-in-vogtle-cost-proceedings-georgians-should-not-bear-financial-burden-of-georgia-powers-project-mismanagement-300550250.html, accessed 7 September 2022.

reactors begin generating electricity.[879] As a result of further delays since then, those costs—and thus customer subsidies—have risen further still, to US$926 per household.[880] With Unit 3 beginning commercial operation, ratepayers will begin paying the full operating cost of the reactor, which is expected to result in a further household electricity cost increase of US$5 per month.[881] The total cost increase when Unit 4 enters commercial operation is expected to be US$14.10 per month for the first five years, falling to US$13.20/month for the following five years.[882]

Under the financing terms agreed with the Georgia PSC, the longer the Vogtle plant takes to construct, the higher its costs, which have invariably been passed on to Georgia ratepayers, resulting in higher income streams for Georgia Power and therefore Southern. In reporting 2018 Southern earnings, CEO Thomas A. Fanning stated that "2018 was a banner year for Southern Company (…). All of our state-regulated electric and gas companies delivered strong performance" with full-year 2018 earnings of US$2.23 billion, compared with earnings of US$842 million in 2017.[883]

Past WNISR editions reported extensively on the economics of the Vogtle project. According to an expert testimony to the PSC on 5 June 2020,

> The Staff CTC [cost to complete] analyses, which ignore the [US]$8.1 billion already incurred by the Company [Georgia Power] as of December 31, 2019, indicate that it is economic to complete the Project if the Company adheres to its current construction cost and the November 2021 and November 2022 regulatory COD [Commercial Operation Date] forecasts. The Staff analyses indicate that it is not economic to complete the Project if there is a delay of 24 months or longer beyond the current regulatory CODs.[884]

879 - Jeff Amy, "Georgia Power seeks $235M boost to pay for nuclear plant", *The Associated Press*, 17 June 2021, see https://apnews.com/article/ga-state-wire-fl-state-wire-al-state-wire-georgia-environment-and-nature-6a0331ea0f7f99b7cac285f20a83a244, accessed 5 September 2022.

880 - Tom Newsome, Philip Hayet, Lane Kollen, "In the Matter Of: Georgia Power Company's Twenty-Eighth Semi-Annual Vogtle Construction Monitoring ('VCM') Report—Direct Testimony and Exhibits", on Behalf of the Georgia Public Service Commission Public Interest Advocacy Staff, Before the Georgia Public Service Commission, 22 June 2023, see https://services.psc.ga.gov/api/v1/External/Public/Get/Document/DownloadFile/204891/86214, accessed 26 August 2023.

881 - Erica Van Buren, "Georgia Power customers to see rate increase with Plant Vogtle Unit 3 now operational", *Augusta Chronicle*, 3 August 2023, see https://eu.augustachronicle.com/story/news/environment/2023/08/03/georgia-power-announced-that-plant-vogtles-unit-3-is-operational-customers-will-see-rate-increase/70508466007/, accessed 26 August 2023.

882 - Drew Kann, "The numbers behind Georgia's new nuclear reactors", *The Atlanta Journal-Constitution*, 31 July 2023, see https://www.ajc.com/news/the-numbers-behind-georgias-new-nuclear-reactors/YXX5GAGKFNDMNJHHKPXTZ6FNYA/, accessed 5 August 2023.

883 - Southern Company, "Southern Company reports fourth-quarter and full-year 2018 earnings", Press Release, as published on *PR Newswire*, 20 February 2019, see https://www.prnewswire.com/news-releases/southern-company-reports-fourth-quarter-and-full-year-2018-earnings-300798574.html, accessed 28 May 2019.

884 - Georgia Public Service Commission Public Interest Advocacy Staff, "In The Matter Of: Georgia Power Company's Twenty-Second Semiannual Vogtle Construction Monitoring ("VCM") Report – Direct Testimony And Exhibits Of Tom Newsome, PE, CFA; Philip Hayet; Lane Kollen, CPA, CMA, CGMA – On Behalf Of The Georgia Public Service Commission Public Interest Advocacy Staff", Before the Georgia Public Service Commission, Docket No. 29849, 5 June 2020.

There were major doubts before 2021 that Georgia Power would meet its COD target dates, but they were confirmed during 2020–2021, including in relation to the start and completion of Hot Functional Tests (HFT).[885] Credit-rating agency Moody's said in a statement:

> The unexpected, late-stage changes to these planned activities is credit negative for Georgia Power because it signals that challenges with the project continue, increasing the likelihood of additional cost overruns and further schedule delays.[886]

While COVID-19 impacted workers on the site, delays were also caused by the need to replace electrical components and other work that the "company decided wasn't up to standard." According to May 2021 press reports, Georgia Power told Commissioners that there was evidence "that contractors were declaring work complete without testing for deficiencies, relying on inspectors to catch it and fix any problems later."[887]

The Georgia PSC Staff's 2020 assessment appears to have borne out, as a result of the further cost increases in the final years of construction In June 2023, as Unit 3 was undertaking startup operations and unit 4 was completing construction and preparing to submit its ITAACs inspection reports, the staff's witnesses testified that the project's costs now exceed the estimated economic benefits to consumers:

> Q: How have the capital and financing cost increases since certification impacted the economic benefit of the units for ratepayers?
>
> A: The cost increases and schedule delays have completely eliminated any benefit on a life-cycle cost basis.

Georgia Power is currently expected to recover approximately US$4.2 billion under the Nuclear Construction Cost Recovery ("NCCR") tariffs imposed on customers during the construction period, or as summarized during expert testimony before the Georgia PSC: "This is nearly double the [US]$2.1 billion the Company would have collected if the Units had been completed in April 2016 and 2017 in accordance with the certification schedule."[888] Of Georgia Power's US$9.1 billion share of the cost overruns, the utility has announced it has written off US$3.26 billion and will seek to recover US$5.7 billion. Georgia PSC staff estimate that Georgia Power would collect US$9.4 billion in profit over 60 years if allowed to recover all of the costs it is seeking.[889]

885 - HFT is a series of tests in which essentially the entire plant is tested in an integrated fashion. The Reactor Coolant System (RCS) is heated in steps to the normal operating temperature and pressure (NOT and NOP) by running the Reactor Coolant Pumps. Significant tests include measurement of thermal expansion and vibrations of the RCS, verifying the ability to control RCS pressure using the pressurizer heaters and spray, and integrated operation of the secondary plant including supplying feedwater to the Steam Generators via the condensate and feedwater systems. In addition, the main turbine will be rolled to full operating speed of 1800 RPM to verify the operation.

886 - Joniel Cha, "Resequencing of Vogtle nuclear plant expansion activities is credit negative: Moody's", S&P Global, 24 June 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/062420-resequencing-of-vogtle-nuclear-plant-expansion-activities-is-credit-negative-moodys, accessed 4 July 2020.

887 - Jeff Amy, "Georgia nuclear plant now delayed until 2022 as costs mount", *The Associated Press*, 18 May 2021, see https://apnews.com/article/georgia-government-and-politics-business-af08e2b3402785febe3c7bf24c65cf2c, accessed 7 September 2022.

888 - Tom Newsome, Philip Hayet, Lane Kollen, "In The Matter Of: Georgia Power Company's Twenty-Seventh Semi-Annual Vogtle Construction Monitoring ("VCM") Report—Direct Testimony And Exhibits of Tom Newsome, PE, CFA, Philip Hayet, Lane Kollen, CPA, CMA, CGMA", on behalf of the Georgia Public Service Commission Public Interest Advocacy Staff, before the Georgia PSC, 3 January 2023, see https://services.psc.ga.gov/api/v1/External/Public/Get/Document/DownloadFile/192559/74336, accessed 16 August 2023.

889 - Jeff Amy, "Georgia nuclear rebirth arrives 7 years late, $17B over cost", *The Associated Press*, 25 May 2023, see https://apnews.com/article/georgia-nuclear-power-plant-vogtle-rates-costs-75c7a413cda3935dd551be9115e88a64, accessed 19 August 2023.

Lawsuits Against the Vogtle Project

Multiple lawsuits against the Vogtle project initiated have continued through the courts. In 2022, Oglethorpe and Municipal Electric Authority of Georgia (MEAG) filed suits against Georgia Power to enforce the terms of the 2018 settlement that allowed the project to continue after Westinghouse's bankruptcy and cost increases to US$25 billion.[890] At issue is a dispute over the allocation of recent cost increases for the project. Oglethorpe and MEAG claim that cost increases have surpassed the threshold at which Georgia Power would begin absorbing 100 percent of the costs and taking a greater ownership share of the reactors, as promised. Georgia Power disputes their argument, claiming that the cost baseline should be US$1.3 billion greater than the US$17.1 billion amount Oglethorpe and MEAG claim. The disputes center on US$695 million in expenses for which Georgia Power has billed the two co-owners. In August 2022, Jacksonville Electric Authority (JEA) wrote to MEAG requesting that it exercise its option in the 2018 agreement to tender a portion of its ownership share of the reactors to halt further payments for cost increases. In order to do so, all 39 of MEAG's member utilities must agree. JEA is not a member of MEAG and cannot vote on the matter but signed a contract with MEAG in 2008 for a stake in its share of Vogtle-3 and -4.[891] The fourth and smallest co-owner, Dalton Utilities, has not sued Georgia Power, but its board voted on 18 July 2022 to exercise its tender option and end its capital spending on Vogtle-3 and -4.[892] Whatever the outcome of the Oglethorpe and MEAG suits, it is likely that Southern Company will begin assuming an increasing share in ownership of the project going forward. Georgia PSC may not permit cost recovery for the full amount of further cost increases, requiring Southern Company to pass those costs onto its shareholders.

Vogtle Federal Loan Guarantees

Under the terms of the Department of Energy's (DOE) Loan Guarantee Program, owners of nuclear projects can borrow at below-market Federal Financing Bank rates with the repayment assurance of the U.S. Government. DOE loan guarantees permitted Vogtle's owners to finance a substantial portion of their construction costs at interest rates well below market levels, and to increase their debt fraction, which significantly reduced overall financing costs. In justification for the loan guarantee to Vogtle, the Obama administration stated in 2014 that

> … the Vogtle project represents an important advance in nuclear technology, other innovative nuclear projects may be unable to obtain full commercial financing due to the perceived risks associated with technology that has never been deployed at commercial scale in the U.S. The loan guarantees from this draft solicitation would support advanced nuclear energy technologies that will catalyze the deployment of future projects that replicate or extend a technological innovation.[893]

890 - Jeff Amy, "Co-owners sue Georgia Power in $695M Vogtle contract dispute", *The Associated Press*, 22 June 2022, see https://apnews.com/article/politics-lawsuits-florida-georgia-a0eaf5c77e77e2b6ba95f0ad93137572, accessed 16 August 2023.

891 - Mike Mendenhall, "JEA's plan for Plant Vogtle savings", *Jacksonville Daily Record*, 2 September 2022, see https://www.jaxdailyrecord.com/news/2022/sep/02/jeas-plan-for-plant-vogtle-savings/, accessed 16 August 2023.

892 - Charles Oliver, "Dalton Utilities ceases spending on nuclear power units at Plant Vogtle", *Dalton Daily Citizen*, 20 July 2022, see https://www.dailycitizen.news/news/local_news/dalton-utilities-ceases-spending-on-nuclear-power-units-at-plant-vogtle/article_fb1c7484-0776-11ed-91af-cfb7e83d9d71.html, accessed 5 September 2022.

893 - Peter W. Davidson, "Fostering the Next Generation of Nuclear Energy Technology—Investing in American Energy", Loan Programs Office, U.S. DOE, 29 September 2014, see https://energy.gov/lpo/articles/fostering-next-generation-nuclear-energy-technology, accessed 6 July 2020.

The loan-guarantee program has therefore played a critical role in permitting the Vogtle project to proceed but has failed to catalyze a nuclear revival, with no prospects of further new large nuclear plants being built in the foreseeable future. Oglethorpe Power Corporation (OPC), which has a 30-percent stake in Vogtle, confirmed in August 2017 that it had submitted a request to DOE for up to US$1.6 billion in additional loan guarantees. The company already had a US$3 billion loan guarantee from DOE. [894] The other owners—Georgia Power and Municipal Electric Authority of Georgia (MEAG)—had secured US$8.3 billion in separate loan guarantees from DOE since 2010, when they were approved by the Obama administration.[895] Both companies confirmed in August 2017 that they were seeking additional loan guarantee financing.

On 29 September 2017, DOE Secretary Perry announced approval of additional US$3.7 billion loan guarantees for the Vogtle owners, with US$1.67 billion to Georgia Power, US$1.6 billion to OPC, and US$415 million to MEAG.[896] A decision on terminating the Vogtle project would have raised the prospect of default on the previous US$8.3 billion loan to Southern.[897] In April 2019, the DOE provided the additional loan guarantee of US$3.7 billion to Plant Vogtle construction[898] bringing the total loan guarantees provided for the Vogtle project by the DOE to US$12.03 billion.[899]

Criminal Investigations of Nuclear Power Corporations

Since 2017, the U.S. Justice Department has opened three separate investigations against utility corporations over criminal activities related to nuclear power. The cases have resulted in indictments of executives, lobbyists, and state officials. The cases have been accompanied by additional lawsuits and state-level investigatory proceedings, and they have had political ramifications which appear to have had further impacts on the industry, economically, as well as legally and politically. Through enactment of the IIJA and IRA, the authorization of an unprecedented amount of federal direct support for commercial nuclear energy over the previous 12 months is, nevertheless, testimony to the extent of political activity by the industry.

894 - Taxpayers for Common Sense, "Vogtle Owner Asking for $1.6 Billion More in Loan Guarantees", 29 August 2017, see https://www.taxpayer.net/energy-natural-resources/vogtle-owner-asking-for-1-6-billion-more-in-loan-guarantees/, accessed 7 September 2022.

895 - Sonal Patel, "DOE Issues Remaining $1.8B in Loan Guarantees for Vogtle Nuclear Reactors", *POWER Magazine*, see https://www.powermag.com/doe-issues-remaining-1-8b-in-loan-guarantees-for-vogtle-nuclear-reactors/, accessed 7 September 2022.

896 - U.S.DOE, "Secretary Perry Announces Conditional Commitment to Support Continued Construction of Vogtle Advanced Nuclear Energy Project", 29 September 2017, see https://www.energy.gov/articles/secretary-perry-announces-conditional-commitment-support-continued-construction-vogtle, accessed 12 August 2020.

897 - Peter Maloney, "Westinghouse bankruptcy puts $8.3B in federal loan guarantees for Vogtle plant at risk", *Utility Dive,* 3 April 2017, see http://www.utilitydive.com/news/westinghouse-bankruptcy-puts-83b-in-federal-loan-guarantees-for-vogtle- pl/439508/, accessed 28 May 2019.

898 - Jacqueline Toth, "DOE Program's $3.7 Billion Loan Highlights Lack of Action on Other $40 Billion It Holds", *Morning Consult,* 8 April 2019, see https://morningconsult.com/2019/04/08/doe-programs-3-7-billion-loan-highlights-lack-of-action-on-other-40-billion-it-holds/, accessed 7 September 2022.

899 - Taxpayers for Common Sense, "DOE Loan Guarantee Program: Vogtle Reactors 3 & 4", 21 March 2019, see https://www.taxpayer.net/wp-content/uploads/2019/03/3-21-19-ENR-Vogtle-Fact-Sheet_MARCH-2019_-v.4.pdf, accessed 10 May 2019.

In total, nuclear utilities, nuclear generation companies, and their major trade groups reported over US$192 million in lobbying expenses at the federal level in 2021 and 2022.[900]

Fraud Investigation and Prosecutions over V.C. Summer Project

> *"Due to this fraud, an $11 billion nuclear ghost town, paid for by SCANA investors and customers, now sits vacant in Jenkinsville, S.C. [South Carolina]. Hopefully, this prosecution will deter other corporate fraud in the future."*
>
> Acting U.S. Attorney M. Rhett DeHart
>
> October 2021[901]

As reported in previous WNISR editions, the decision on 31 July 2017 by Santee Cooper and SCANA Corporation (the parent company of South Carolina Electric & Gas or SCG&E) to terminate construction of the V.C. Summer reactor project has seen ongoing financial and legal fallout for the companies and ratepayers of South Carolina during the subsequent six years. At the time of cancellation, the total cost for completion of the two AP-1000 reactors at V.C. Summer was projected to exceed US$25 billion[902]—about 2.5 times the initial estimate.[903] The conspiracy to deceive regulators and ratepayers, which has been revealed by federal investigations, was intended to allow SCANA to apply for numerous rate increases to help pay for ongoing reactor construction. The rate increases were "fraudulently inflated bills to customers for the stated purpose of funding the project," according to federal filings from 2020.[904] Under legislation passed by the South Carolina state Legislature in 2007[905]—strongly opposed by civil society groups—construction costs for the V.C. Summer reactors were to be paid by state ratepayers.[906] When SCANA was taken over by Dominion Energy in January 2019, it "committed to make extensive remedial efforts to redress ratepayers," which was estimated

900 - Search of lobbying disclosure reports from U.S. Senate, as of 12 May 2023; for the following clients: Ameren, American Electric Power, Berkshire Hathaway Energy, BCitizens for Responsible Energy Solution, Constellation Energy, Dominion Energy, Dominion Resources, DTE Energy, Duke Energy, Edison Electric Institute, Edison International, Energy Harbor, Evergy, Exelon, FirstEnergy, Nextera Energy, NRG Energy, Nuclear Energy Institute, Pacific Gas and Electric, Pacific Gas & Electric, Pinnacle West, PSEG, Southern Company, Entergy, PSEG, Sempra Energy, Talen Energy, Vistra, and Xcel Energy.
See U.S. Senate, "Lobbying Disclosure", Undated, see https://lda.senate.gov/filings/public/filing/search/, accessed 12 May 2023

901 - U.S. Attorney's Office for the District of South Carolina, "Former SCANA CEO Sentenced to Two Years for Defrauding Ratepayers in Connection with Failed Nuclear Construction Project", Press Release, U.S. Department of Justice, 7 October 2021, see https://www.justice.gov/usao-sc/pr/former-scana-ceo-sentenced-two-years-defrauding-ratepayers-connection-failed-nuclear, accessed 27 August 2023.

902 - Brad Plummer, "U.S. Nuclear Comeback Stalls as Two Reactors Are Abandoned", *The New York Times*, 31 July 2017, see https://www.nytimes.com/2017/07/31/climate/nuclear-power-project-canceled-in-south-carolina.html, accessed 16 August 2023.

903 - Jan Horst Keppler and Marco Cornetto, "Nuclear New Build: Insights into Financing and Project Management", NEA No. 7195, Division of Nuclear Development, Nuclear Energy Agency, Organisation for Economic Co-Operation and Development, 2015, pp. 219-224, see https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/7195-nn-build-2015.pdf, accessed 5 September 2022.

904 - District Court of the United States for the District of South Carolina, "United States Vs Stephen Andrew Byrne—Plea Agreement", Criminal No 3:20 355, 21 May 2020, Filed 8 June 2020, see https://srswatch.org/wp-content/uploads/2020/06/Byrne-court-plea-June-8-2020.pdf; and John Monk, "SCANA conspirators helped Byrne spin lies about nuclear project, document alleges", *The State,* Updated 15 June 2020, see https://www.thestate.com/news/local/crime/article243395241.html, both accessed 6 July 2020.

905 - South Carolina General Assembly, "Act No. 16—Base Load Review Act", enacted 3 May 2007, see https://www.scstatehouse.gov/sess117_2007-2008/bills/431.htm, accessed 5 September 2022.

906 - Akela Lacy, "South Carolina Spent $9 Billion to Dig a Hole in the Ground and Then Fill It Back In", *The Intercept*, 6 February 2019, see https://theintercept.com/2019/02/06/south-caroline-green-new-deal-south-carolina-nuclear-energy/, accessed 5 September 2022.

to be approximately US$4 billion.[907] Exactly what this means remains unclear, as under current plans, Dominion will be charging South Carolina ratepayers an additional US$2.3 billion over the next two decades for the collapsed V.C. Summer project.[908] The 8 June 2020 filing made it clear that Dominion will not be prosecuted, with a utility spokesman stating, "We have no further comment regarding this matter or the investigation".[909]

Executives from both SCANA and Westinghouse were found guilty of unlawfully withholding information for years about the failure of the V.C. Summer project both from regulators and shareholders. On 7 October 2021, former SCANA CEO Kevin Marsh was sentenced to two years in prison after pleading guilty to charges of conspiracy to commit mail and wire fraud. Under his plea agreement, he paid US$5 million in "federal forfeiture". Marsh was the first defendant to be sentenced, and was reportedly released in March 2023, after 17 months of his prison sentence.[910]

Three others have pleaded guilty to having participated in an illegal abuse of public trust by engaging in a deliberate plan to hide the extent of SCANA's financial troubles at the nuclear project from the public, from regulators, and from investors in the publicly traded utility.

Stephen Byrne, former Chief Operating Officer (COO) of SCANA, who faced a five-year prison sentence, was sentenced to 15 months in prison in March 2023, and will pay back "[US]$1 million in ill-gotten income" he received after lying about the Summer reactors' construction-status in 2016, in addition to paying a US$200,000 fine.[911]

In the case brought against Carl Dean Churchman, former Vice President of Westinghouse Electric Corporation and the director of the V.C. Summer project for the company, it was found that he was communicating "with colleagues from the Westinghouse Electric Corporation through multiple emails in which they discussed the viability and accuracy of (completion dates) and thereafter, he reported those dates to executives of SCANA and Santee Cooper during a meeting held on Feb. 14, 2017."[912] On 10 June 2021, Churchman pleaded guilty to the felony offence of lying to the Federal Bureau of Investigation (FBI).[913] As of 31 July 2023, he still awaits sentencing.

Acting U.S. Attorney Rhett DeHart stated in June 2021, "This guilty plea shows that the investigation into the V.C. Summer nuclear debacle did not end with the former SCANA

907 - Joniel Cha, "Former Scana executive to plead guilty to fraud over Summer nuclear project", *Nucleonics Week*, 11 June 2020.

908 - Avery G. Wilks and Andrew Brown, "Ex-SCE&G official will cooperate as witness in criminal probe of failed VC Summer project", *The Post and Courier*, 9 June 2020, see https://www.postandcourier.com/business/ex-sce-g-official-will-cooperate-as-witness-in-criminal-probe-of-failed-vc-summer/article_e8a99396-aa4d-11ea-bcb3-77378b75c486.html, accessed 6 July 2020.

909 - Ibidem.

910 - Avery G. Wilks, "Former SCANA executive gets prison time for role in VC Summer fraud", *Post and Courier*, 8 March 2023, see https://www.postandcourier.com/news/former-scana-executive-gets-prison-time-for-role-in-vc-summer-fraud/article_cdb14a62-bd09-11ed-a361-57b7dc362333.html, accessed 4 August 2023.

911 - Ibidem

912 - John Monk, "Former Westinghouse official to plead guilty in FBI probe of SCANA's nuclear failure", *The State*, 24 May 2021, see https://www.thestate.com/news/politics-government/article251639033.html, accessed 20 July 2021.

913 - U.S. Attorney's Office for the District of South Carolina, "Westinghouse Director During Nuclear Debacle Pleads Guilty in Federal Court to Making False Statement to FBI", Press Release, U.S. Department of Justice, 10 June 2021, see https://www.justice.gov/usao-sc/pr/westinghouse-director-during-nuclear-debacle-pleads-guilty-federal-court-making-false, accessed 16 August 2023.

executives," and added, "We are committed to seeing this case through and holding all individual and corporate wrongdoers accountable."[914]

On 9 May 2022, a procedural ruling was reported to clear the way for the trial of former Westinghouse Vice President Jeffrey Benjamin in a sixteen-count felony criminal indictment.[915] The court ruled that Benjamin could continue using an attorney who also represented another former Westinghouse executive who is cooperating with prosecutors. The trial of Benjamin was expected to begin as soon as October 2022 as a result of the ruling. However, a judge threw out the case on 2 August 2023, ruling that the grand jury that indicted Benjamin was biased, because it included jurors who were SCANA ratepayers who had been harmed by SCANA and Westinghouse's actions. Judge Lewis said in her ruling:[916]

> It is common sense that in a robbery case, the person who allegedly had their belongings taken would be barred, as a victim, from participating in indicting the accused, no matter if there was a mountain of evidence against the accused or if the victim insisted they could remain impartial.

The judge affirmed that prosecutors could seek another indictment. Prosecutors indicated they had not decided yet how they will proceed, but explicitly stated, "We're not going away".[917]

A parallel legal case, brought by the Securities and Exchange Commission (SEC) against SCANA was settled in December 2020. The same executives (Marsh and Byrne) were charged along with SCANA, accused of civil fraud and being at the center of a scheme that artificially inflated SCANA's stock price in the period 2014–2017. The proposed settlement, announced by the SEC on 2 December 2020, required SCANA to pay a US$25 million civil penalty, and SCANA and SCE&G to pay US$112.5 million in disgorgement plus prejudgment interest, which the companies agreed to pay "without admitting or denying the allegations." [918] Marsh and Byrne also plead guilty in the SEC case in 2021.[919]

Ohio Corruption Scandal and Nuclear Subsidy Legislation

In July 2020, the speaker of the Ohio House of Representatives, Larry Householder, was arrested by the FBI on charges of racketeering. Also indicted were four lobbyists, political operatives, and associates of Householder, who—initially—all pleaded not guilty:[920]

914 - Attorney's Office for the District of South Carolina, "Westinghouse Director During Nuclear Debacle Pleads Guilty in Federal Court to Making False Statement to FBI", Press Release, U.S. Department of Justice, 10 June 2021, see https://www.justice.gov/usao-sc/pr/westinghouse-director-during-nuclear-debacle-pleads-guilty-federal-court-making-false, accessed 27 August 2023.

915 - John Monk, "Judge lets ex-Westinghouse official keep lawyer, clearing way for SC's last SCANA fraud trial", *The State*, 10 May 2022, see https://www.thestate.com/news/local/crime/article261298847.html, accessed 5 September 2022.

916 - Jeffrey Collins, "Judge tosses charges against executive in South Carolina nuclear debacle, but case may not be over", *The Associated Press*, 3 August 2023, see https://apnews.com/article/westinghouse-nuclear-scana-failed-jeffrey-benjamin-2a8ad7c75075d015ba2262b9dbf6ac53, accessed 16 August 2023.

917 - Ibidem.

918 - SEC, "Securities and Exchange Commission v. SCANA Corporation, et al., No. 3:20-cv-00882-MGL (D.S.C., filed December 2, 2020)", Litigation Release No. 24976, 3 December 2020, see https://www.sec.gov/litigation/litreleases/2020/lr24976.htm, accessed 20 July 2021.

919 - U.S. Attorney's Office for the District of South Carolina, "Former SCANA CEO Pleads Guilty To Conspiracy to Commit Mail and Wire Fraud", Press Release, United States Department of Justice, 24 February 2021, see https://www.justice.gov/usao-sc/pr/former-scana-ceo-pleads-guilty-conspiracy-commit-mail-and-wire-fraud, accessed 4 August 2023.

920 - Andrew Welsh-Huggins, "4 Ohio operatives plead not guilty in $60M bribery probe", *The Associated Press*, 6 August 2020, see https://apnews.com/article/ohio-columbus-racketeering-government-and-politics-cf2b377370605cdf5e9bc165635e2b08, accessed 16 August 2023.

- Lobbyist and former Ohio Republican Party Chair, Matt Borges;
- Juan Cespedes, an outside lobbyist for FirstEnergy;
- Jeff Longstreth, an associate of Householder and director of the Generation Now political action committee (PAC) that served as one of the main vehicles of the corruption scheme; and
- Neil Clark, head of the largest lobbying firm in Ohio and ally of Householder.

It was alleged at the time that Householder and his associates had set up a US$60 million slush fund

> to elect their candidates, with the money coming from one of the state's largest electricity companies. (...) Prosecutors contend that in return for the cash, Mr. Householder, a Republican, pushed through a huge bailout of two nuclear plants and several coal plants that were losing money.[921]

As a result of the leadership role of Householder, in 2019, legislation House Bill 6 (HB6)[922] was passed and FirstEnergy's Davis-Besse and Perry plants were granted subsidies totaling US$1.05 billion of electricity-customer money to support keeping their uneconomic units on the grid. The conspiracy was "likely the largest bribery, money-laundering scheme ever perpetrated against the people of the state of Ohio," the U.S. attorney for the Southern District of Ohio, David M. DeVillers, said in a news conference in 2020.[923] In the three years since, the scandal has escalated, leading to Generation Now pleading guilty to federal racketeering charges in February 2021, and forfeiting US$1.5 million;[924] the admission of guilt by FirstEnergy in July 2021; the corporation's payment of a US$230 million penalty and its commitment to cooperate with the investigation;[925] and the enactment of a bill in 2021 repealing the nuclear subsides and a profiteering ratemaking provision in HB6, while leaving in place a smaller subsidy program for two coal plants and provisions that effectively ended energy efficiency and renewable energy standards.[926]

Neil Clark died by suicide a few months after his indictment, and in October 2020, Cespedes and Longstreth pleaded guilty to their roles in the corruption scheme and testified for

921 - Justin Gillis, "Opinion—When Utility Money Talks", *The New York Times*, 2 August 2020, see https://www.nytimes.com/2020/08/02/opinion/utility-corruption-energy.html, accessed 29 August 2020.

922 - Ohio Legislature, "House Bill 6: Creates Ohio Clean Air Program", 22 October 2019, see https://www.legislature.ohio.gov/legislation/legislation-summary?id=GA133-HB-6, accessed 5 September 2022.

923 - Giulia McDonnell Nieto del Rio, "Powerful Ohio Republican Is Arrested in $60 Million Corruption Scheme", *The New York Times*, 21 July 2020, see https://www.nytimes.com/2020/07/21/us/larry-householder-ohio-speaker-arrested.html, accessed 29 August 2020.

924 - Julie Carr and Mark Gillispie, "Dark money group admits racketeering in Ohio bribery case", *The Associated Press*, 19 February 2021, see https://apnews.com/article/ohio-columbus-mike-dewine-196cd6a1f17fe53032ecb36789c7a3fe, accessed 19 August 2023.

925 - Mark Gillispie, Julie Carr Smyth and Farnoush Amiri, "FirstEnergy to pay $230M in agreement in Ohio bribery case", *The Associated Press*, 23 July 2021, see https://apnews.com/article/business-government-and-politics-ohio-a4dd75020561d8b533fdabcb98a0a350, accessed 3 August 2023.

926 - Jeremy Pelzer, "Gov. Mike DeWine signs repeal of nuclear bailout, other parts of scandal-tainted House Bill 6", *Cleveland.com*, 31 March 2021, see https://www.cleveland.com/open/2021/03/gov-mike-dewine-signs-repeal-of-nuclear-bailout-other-parts-of-scandal-tainted-house-bill-6.html, accessed 5 September 2022.

the prosecution.[927] In March 2023, Householder and Borges were convicted of conspiracy, racketeering, bribery, and money laundering.[928] In June 2023, Householder was sentenced to the maximum of 20 years, and Borges to five years.[929] Both of them are appealing their sentences.[930]

In October 2020, when FirstEnergy was still denying its guilt, it continued its efforts to prevent further disclosures, leading Miranda Leppla, Vice President of Energy Policy for the Ohio Environmental Council Action Fund, to state, "FirstEnergy's lack of transparency is a continuation from its resistance to prove it even needed the bailout it received in House Bill 6, despite requests from lawmakers during HB 6 hearings."[931]

Tom Bullock, executive director of the Citizen Utility Board, warned that "Ohio consumers have been harmed by HB 6, and the damage gets much worse on January 1 [2021] when US$150 million [in] nuclear bailout charges kick in…FirstEnergy says it's not complicit in alleged HB 6 bribery, but it's using legal maneuvers to block transparency, deny consumer refunds, and keep nuclear bailout money. Consumers need PUCO [Public Utilities Commission of Ohio] to side with us and order FirstEnergy to cooperate."[932]

On 16 November 2020, FBI agents raided the home of PUCO Chairman Sam Randazzo. He was appointed by Governor DeWine in February 2019, prior to which he was a longtime lawyer for the utility industry. In mid-July 2021, it was disclosed that FirstEnergy admitted in a deferred prosecution agreement that it paid Randazzo US$22 million between 2010 and 2019, prior to his appointment to chair of PUCO. PUCO, also in November 2020, began an audit of FirstEnergy

927 - U.S. Attorney's Office for the Southern District of Ohio, "Political strategist & lobbyist each plead guilty in federal public corruption racketeering conspiracy involving more than $60 million", Press Release, United States Department of Justice, 29 October 2020, see https://www.justice.gov/usao-sdoh/pr/political-strategist-lobbyist-each-plead-guilty-federal-public-corruption-racketeering; and *AP News*, "Ohio ex-speaker ill, corruption trial pauses after big week", *The Associated Press*, 19 February 2023, see https://apnews.com/article/ohio-state-government-crime-cincinnati-columbus-91f04d1ad1169ea59dee9e7cfb96263e; both accessed 3 August 2023.

928 - U.S. Attorney's Office for the Southern District of Ohio, "Jury convicts former Ohio House Speaker, former chair of Ohio Republican Party of participating in racketeering conspiracy", Press Release, U.S. Department of Justice, 9 March 2023, see https://www.justice.gov/usao-sdoh/pr/jury-convicts-former-ohio-house-speaker-former-chair-ohio-republican-party, accessed 19 August 2023.

929 - U.S. Attorney's Office for the Southern District of Ohio, "Former Ohio House Speaker sentenced to 20 years in prison for leading racketeering conspiracy involving $60 million in bribes", Press Release, U.S. Department of Justice, 29 June 2023; and U.S. Attorney's Office for the Southern District of Ohio, "Former chair of Ohio Republican Party sentenced to 5 years in prison for role in racketeering conspiracy", Press Release, U.S. Department of Justice, 30 June 2023; also Jessie Balmert and Laura A. Bischoff, "Ex-Ohio GOP leader Matt Borges sentenced to 5 years in prison", *The Columbus Dispatch*, as published by *The Enquirer*, 29 June 2023, see https://www.cincinnati.com/story/news/politics/2023/06/29/ex-ohio-gop-leader-matt-borges-faces-sentencing-in-corruption-case/70235398007/, accessed 19 August 2023.

930 - Jake Zuckerman, "Ex-Ohio House Speaker Larry Householder appeals bribery conviction that got him 20 years in prison", *Cleveland.com*, 12 July 2023, see https://www.cleveland.com/open/2023/07/ex-ohio-house-speaker-larry-householder-appeals-bribery-conviction-that-got-him-20-years-in-prison.html; and *KDKA News*, "Prominent lobbyist appeals 5-year prison sentence in historic Ohio corruption scheme", as published by *CBS Pittsburgh*, 15 July 2023, see https://www.cbsnews.com/pittsburgh/news/matt-borges-lobbyist-appeals-prison-sentence-ohio-corruption/; both accessed 16 August 2023.

931 - Kathiann M. Kowalski, "FirstEnergy fights against disclosing more details about alleged HB 6 bribery cases", *Energy News Network*, 30 October 2021, see https://energynews.us/2020/10/30/firstenergy-fights-against-disclosing-more-details-about-alleged-hb-6-bribery-cases/, accessed 12 August 2021.

932 - Ibidem.

to see whether the company broke any laws or regulations regarding its interactions with an ex-subsidiary while the companies pushed to secure HB6.[933]

On 29 December 2020, the Ohio Supreme Court ordered a halt to electric utilities collecting monthly fees under HB6.[934] In March 2021, FirstEnergy informed Ohio regulators that it would refuse to refund customers US$30 million collected from revenue generated under the HB6 legislation.[935] The Ohio Consumers' Counsel had called on the Ohio PUCO to order FirstEnergy to "remedy what would be a miscarriage or perversion of justice" were the company to keep income from rate guarantees. "As we see it, the PUCO or the legislature shouldn't allow FirstEnergy to walk away from the House Bill 6 scandal with even a penny of Ohioans' money, and certainly not with the US$30 million it charged consumers for recession-proofing," the Consumers' Counsel said in a statement.[936]

On 31 March 2021, Ohio Governor DeWine signed House Bill 128, which permanently canceled nuclear power subsidies paid under HB6.[937] On the same day, FirstEnergy reversed its previous position and agreed to refund US$26 million to consumers for charges it collected through HB6.[938]

On 22 July 2021, it was announced that FirstEnergy had signed a deferred prosecution agreement (DPA) and agreed to pay a US$230 million fine for bribing key Ohio officials in its efforts to secure the HB6 US$1-billion ratepayer-funded bailout for two nuclear plants. The U.S. Department of Justice detailed in court filings that FirstEnergy had admitted that

> it conspired with public officials and other individuals and entities to pay millions of dollars to public officials in exchange for specific official action for FirstEnergy Corp.'s benefit.
>
> FirstEnergy Corp. acknowledged in the deferred prosecution agreement that it paid millions of dollars to an elected state public official through the official's alleged 501(c)(4) in return for the official pursuing nuclear legislation for FirstEnergy Corp.'s benefit.
>
> (…)

933 - Jeremy Pelzer, "FBI searches Public Utilities Commission of Ohio Chairman Sam Randazzo's home", *Cleveland.com*, 16 November 2020, see https://www.cleveland.com/open/2020/11/fbi-searches-public-utilities-commission-of-ohio-chairman-sam-randazzos-home.html; and Laura A. Bischoff, "Top state regulator paid millions for part-time work, FirstEnergy agreement shows", *The Columbus Dispatch*, 2 August 2021, see https://eu.dispatch.com/story/news/2021/08/02/firstenergy-paid-sam-randazzo-big-money-work-part-time/5436419001/; both accessed 12 August 2021.

934 - *ABC6*, "Ohio Supreme Court issues order stopping electric utilities from collecting monthly fee", 29 December 2020, see https://abc6onyourside.com/news/local/ohio-supreme-court-issues-order-stopping-electric-utilities-from-collecting-monthly-fee, accessed 12 August 2021.

935 - Mark Gillespie, "FirstEnergy refusing to return subsidy cash to customers", *The Associated Press*, 20 March 2021, see https://apnews.com/article/akron-ohio-archive-utilities-d2d8b22e574437d91b247b3e693252ef, accessed 12 August 2021.

936 - Ibidem.

937 - Jarrod Clay, "Gov. DeWine signs bill repealing parts of scandal-tainted House Bill 6", *ABC6*, 31 March 2021, see https://abc6onyourside.com/news/local/gov-dewine-signs-bill-repealing-parts-of-scandal-tainted-house-bill-6, accessed 12 August 2021

938 - Julie Carr Smyth and John Seewer, "FirstEnergy refunds $26M as nuclear bailout repeal is signed", *The Associated Press*, 31 March 2021, see https://apnews.com/article/akron-ohio-us-news-legislation-mike-dewine-c1b46983e8c8f8739d056ba12fa35f8d, accessed 16 August 2023.

> FirstEnergy Corp. further acknowledged that it paid [US]$4.3 million dollars to a second public official. In return, the individual acted in their official capacity to further First Energy Corp.'s interests related to passage of nuclear legislation and other company priorities.[939]

The fine is the "largest criminal penalty ever collected, as far as anyone can recall, in the history of this office," acting U.S. Attorney for the Southern District of Ohio Vipal Patel said.[940] However, the fine is less than a quarter of the US$1 billion in earnings in 2020, and FirstEnergy's stock price soared after the three-year deferred prosecution agreement was announced.[941]

The agreement with the Justice Department details how FirstEnergy bought key Ohio public officials—notably former Ohio House Speaker Larry Householder and former PUCO Chairman Sam Randazzo—with millions of dollars funneled through the dark money group Generation Now, controlled by Householder. Between 2017 and March 2020, FirstEnergy Corp. and FirstEnergy Solutions (FES, which was spun off and reconstituted through bankruptcy as Energy Harbor) donated US$59 million to Generation Now and a further US$2 million reportedly to "Householder's effort to expand term limits, potentially giving him 16 more years in power."[942]

The termination of Ohio subsidies for the two reactors at Davis-Besse and Perry did not lead Energy Harbor to issue any public statements indicating it might close the reactors, which are now owned by FirstEnergy Solutions' creditors since the execution of the restructuring and spin-off through the bankruptcy settlement. With the advent of Congress enacting the IIJA and IRA, Energy Harbor's reactors will effectively transition to relying on federal support for their continued operation.

The federal investigation and trial revealed a wider circle of interested parties and unindicted accomplices to the HB6 bailout and corruption scheme. The efforts to pass HB6 were undertaken concurrently with the FirstEnergy Solutions' bankruptcy case. A partner in Akin Gump, the law firm that represented FirstEnergy Solutions in the bankruptcy, submitted a letter to the judge in that case with testimony which reportedly indicate that "FirstEnergy Solutions' management, board, and some top consultants for the utility and its creditors knew about plans to spend over US$40 million on political contributions" to Generation Now.[943]

939 - United States Attorney Office, Southern District of Ohio, "FirstEnergy charged federally, agrees to terms of deferred prosecution settlement", U.S. Department of Justice, 22 July 2021, see https://www.justice.gov/usao-sdoh/pr/firstenergy-charged-federally-agrees-terms-deferred-prosecution-settlement, accessed 12 August 2021.

940 - Scott Noll, "FirstEnergy to pay $230M in settlement in Ohio bribery case", *The Associated Press*, as published on *News5Cleveland*, 22 July 2021, see https://www.news5cleveland.com/news/state/firstenergy-to-pay-230m-in-settlement-in-ohio-bribery-case, accessed 12 August 2021.

941 - Tomi Kilgore, "First Energy stock surges after agreeing to $230 million penalty to resolve DOJ investigation", *MarketWatch*, 22 July 2021, see https://www.marketwatch.com/story/first-energy-stock-surges-after-agreeing-to-230-million-penalty-to-resolve-doj-investigation-2021-07-22, accessed 16 August 2023.

942 - Laura A. Bischoff and Jessie Balmert, "FirstEnergy charged in Ohio bribery scheme, agrees to deferred prosecution settlement for $230 million", *USA Today*, as published on *The Colombus Dispatch*, 22 July 2021, see https://eu.dispatch.com/story/news/politics/2021/07/22/fbi-us-attorney-ohio-public-corruption-development/8052546002/, accessed 12 August 2021.

943 - Dave Anderson, "Who knew about bribes paid during FirstEnergy Solutions' bankruptcy and House Bill 6 bailout campaign?", Energy and Policy Institute, 16 November 2021, see https://energyandpolicy.org/firstenergy-solutions-bribes/, accessed 16 August 2023.

On 2 August 2023, it was reported that FirstEnergy is being investigated by the Ohio Organized Crime Investigations Commission (OCIC) for the HB6 bribery scheme.[944] In a quarterly filing to the U.S. Securities and Exchange Commission (SEC), FirstEnergy disclosed that it received a subpoena from the OCIC in June 2023.[945] The investigation stems from matters included in FirstEnergy's 2021 DPA, but further details have not been reported. FirstEnergy states that it is cooperating with the OCIC inquiry.

The revelations brought to light by the corruption case have also led state and federal regulatory agencies to investigate the sources of the US$61 million with which FirstEnergy financed the bribery scheme. In particular, an investigation by the Maryland Public Service Commission, which regulates FirstEnergy's Potomac Edison utility subsidiary, discovered that the corporation improperly used money collected from Maryland consumers to fund the HB6 scheme.[946] The findings also included FirstEnergy's efforts to get the Trump administration to promote a nationwide bailout for the coal and nuclear industries in 2017, the failure of which led to the HB6 campaign. Potomac Edison made a US$163,000 contribution that year to a Trump-affiliated dark money nonprofit, America First Policies Inc., "just as FirstEnergy was seeking financial and regulatory support from the Trump administration for its struggling nuclear and coal plants, which became the basis for the political scandal in Ohio."[947] In addition, the Federal Energy Regulatory Commission published an audit of FirstEnergy in 2022, which found that the company had "misallocated costs or improperly accounted for" over US$70 million in lobbying and dark money political activities between 2015 and 2021, a period of time encompassing FirstEnergy's series of attempts to win subsidies for its uneconomic nuclear and coal power plants.[948]

FirstEnergy's 2017 effort centered on getting the Trump administration to use executive powers to institute a nationwide subsidy for baseload generation (principally, coal and nuclear power plants) through wholesale electricity market rules in order to prevent alleged grid reliability problems. The DOE initiated a rulemaking proposal at the Federal Energy Regulatory Commission (FERC) in October 2017,[949] which would have provided full cost recovery to power

944 - *KDKA News*, "Ohio-based FirstEnergy says it's being investigated by a state commission", as published on *CBS News*, 3 August 2023, see https://www.cbsnews.com/pittsburgh/news/firstenergy-investigated-state-commission/, accessed 3 August 2023.

945 - FirstEnergy, "Form 10-Q—Quarterly Report Pursuant to Section 13 or 15 (d) of the Securities Exchange Act of 1934—For the Quarterly Period Ended June 30, 2023", filed with the U.S. Securities and Exchange Commission, see https://www.sec.gov/ix?doc=/Archives/edgar/data/1031296/000103129623000054/fe-20230630.htm; and Ethan Howland, "FirstEnergy investigated by Ohio organized crime commission over bribes on energy bill", *Utility Dive*, 3 August 2023, see https://www.utilitydive.com/news/firstenergy-ohio-organized-crime-commission-bribes-earnings/689798/, accessed 3 August 2023.

946 - Josh Kurtz, "Ohio Bribery Scandal Hits Home in Md. — and Utility Customers May Be Footing the Bill", *Maryland Matters*, 21 April 2022, see https://www.marylandmatters.org/2022/04/21/ohio-bribery-scandal-hits-home-in-md-and-utility-customers-may-be-footing-the-bill/, accessed 2 August 2023.

947 - Ibidem.

948 - Office of Enforcement, "FERC enforcement audit of FirstEnergy", Docket No. FA19-1-000, Federal Energy Regulatory Commission, addressed to Jason Lisowski, Vice President, Controller and Chief Accounting Officer, FirstEnergy Corporation, 4 February 2022, see https://www.documentcloud.org/documents/21197493-ferc-enforcement-audit-of-firstenergy, accessed 4 August 2023.

949 - Rick Perry, "Secretary of Energy's Direction that the Federal Energy Regulatory Commission Issue Grid Resiliency Rules Pursuant to the Secretary's Authority Under Section 403 of the Department of Energy Organization Act", Secretary of Energy, U.S. Government, addressed to the Federal Energy Regulatory Commission, 28 September 2017, see https://www.energy.gov/sites/prod/files/2017/09/f37/Secretary%20Rick%20Perry%27s%20Letter%20to%20the%20Federal%20Energy%20Regulatory%20Commission.pdf; and *The Climate Post*, "DOE Secretary Proposes Rule to Aid Coal, Nuclear Plants", as published by Nicholas Institute for Environmental Policy Solutions, Duke University, 5 October 2017, see https://sites.nicholasinstitute.duke.edu/climatepost/2017/10/05/doe-secretary-proposes-rule-to-aid-coal-nuclear-plants/, accessed 2 August 2023.

plants that maintain a 90-day supply of fuel on-site.[950] The commission unanimously rejected the proposal in January 2018.[951]

In the wake of that decision, FirstEnergy raised the prospect that it would seek bankruptcy protection and restructuring of FirstEnergy Solutions, prompting a group of four hedge funds to offer US$2.5 billion in purchasing FirstEnergy shares while advising the company through a restructuring[952] that would spin off the merchant generation business and make FirstEnergy a "pure-play collection of pristine, fully regulated utility companies" according to the executive chairman of Bluescape, one of the investing firms.[953] In March 2018, FirstEnergy called on DOE to use authorities under the Federal Power Act, and order PJM Interconnection to provide cost recovery for the struggling FES nuclear and coal power plants.[954] Shortly thereafter, FirstEnergy filed for FES's bankruptcy and notified the NRC and PJM of its intent to retire its four nuclear reactors.[955] In August 2018, the company announced that it would close its coal plants, as well,[956] by which time the conspiracy with Householder and Generation Now was under way.

The case points to the wider set of monied interests with a stake in the fortunes of the capital-intensive nuclear energy industry and the continued operation of aging and/or uneconomical reactors. State and federal nuclear subsidies also underwrite loans and investments on a growing number of what may otherwise become distressed assets. In the case of FirstEnergy, enactment of the HB6 bailout underwrote a bankruptcy settlement, through which the FES creditors became equity owners of a new standalone company that principally possessed uneconomical nuclear and coal power plants. The Ohio legislature's repeal of the nuclear bailout was likely an unexpected consequence of the federal criminal case; but, four years later, the enactment of IRA and IIJA stands to provide even greater subsidies than HB6 would

950 - Joshua M. Pearce, "Subsidizing coal and nuclear power could drive customers off the grid", *The Conversation*, 15 November 2017, see https://theconversation.com/subsidizing-coal-and-nuclear-power-could-drive-customers-off-the-grid-87159, accessed 30 April 2018.

951 - Joanna Walters, "Energy agency rejects Trump plan to prop up coal and nuclear power plants", *The Guardian*, 8 January 2018, see https://www.theguardian.com/environment/2018/jan/08/donald-trump-coal-industry-plan-rejected-rick-perry, accessed 2 August 2023.

952 - John Funk, "Davis-Besse, Perry nuclear plants could close as FirstEnergy inks deal with hedge funds", *Cleveland.com*, 23 January 2018, see https://www.cleveland.com/business/index.ssf/2018/01/davis-besse_perry_nuclear_plan_1.html, accessed 30 April 2018.

953 - FirstEnergy, "FirstEnergy Announces Transformational $2.5 Billion Equity Investment", Press Release, 22 January 2018, see https://investors.firstenergycorp.com/investor-materials/news-releases/news-details/2018/FirstEnergy-Announces-Transformational-2.5-Billion-Equity-Investment/default.aspx, and Robert Walton, "$2.5B cash infusion will help FirstEnergy shift away from merchant generation", *Utility Dive*, 23 January 2018, see https://www.utilitydive.com/news/25b-cash-infusion-will-help-firstenergy-shift-away-from-merchant-generati/515350/, accessed 16 August 2023.

954 - FirstEnergy Solutions, "RE: Request for Emergency Order Pursuant to Federal Power Act Section 202(c)", addressed to Secretary of Energy, U.S. Department of Energy, 29 March 2018, see https://statepowerproject.files.wordpress.com/2018/03/fes-202c-application.pdf; and Robert Walton and Gavin Bade, "FirstEnergy asks DOE for emergency action to save PJM coal, nuke plants", *Utility Dive*, 29 March 2018, see https://www.utilitydive.com/news/firstenergy-asks-doe-for-emergency-action-to-save-pjm-coal-nuke-plants/520280/, accessed 19 August 2023.

955 - John Funk, "FirstEnergy's power plant company files for bankruptcy protection", *Cleveland.com*, 1 April 2018, see https://www.cleveland.com/business/2018/03/firstenergy_solutions_bankrupt.html, and FirstEnergy, "FirstEnergy Solutions Files Certification Letter with NRC Affirming Plans to Deactivate Three Nuclear Generating Plants", Press Release, as published on *PR Newswire*, 25 April 2018, see https://www.prnewswire.com/news-releases/firstenergy-solutions-files-certification-letter-with-nrc-affirming-plans-to-deactivate-three-nuclear-generating-plants-300636292.html; both accessed 16 August 2023.

956 - FirstEnergy Solutions, "FirstEnergy Solutions Files Deactivation Notice for Oil- and Coal-fired Plants in Ohio and Pennsylvania", Press Release, as published by *PR Newswire*, 29 August 2018, see https://www.prnewswire.com/news-releases/firstenergy-solutions-files-deactivation-notice-for-oil--and-coal-fired-plants-in-ohio-and-pennsylvania-300704459.html; and Robert Walton, "FirstEnergy to retire more than 4 GW of PJM coal plant capacity", *Utility Dive*, 30 August 2018, see https://www.utilitydive.com/news/firstenergy-to-retire-more-than-4-gw-of-pjm-coal-plant-capacity/531300/; both accessed 16 August 2023.

have, and the equity owners of Ex-FirstEnergy Solutions turned Energy Harbor have since secured a US$3.43 billion acquisition offer in the March 2023-deal with Vistra[957]—substantially greater than the US$2.8 billion in FES debts that were restructured through the bankruptcy settlement.[958]

Exelon Corruption Investigation Involving Utility Rate-Setting and Nuclear Subsidies

Federal investigators began a far-ranging investigation into corrupt practices in Illinois as early as 2014.[959] The focus of the investigation on Exelon became evident in 2019 with subpoenas and search warrants being issued to two public officials, an Exelon lobbyist, and a staffer to the Speaker of the Illinois House of Representatives, Michael Madigan.[960] In July 2020, prosecutors with the U.S. Attorney's Office for the Northern District of Illinois announced a Deferred Prosecution Agreement (DPA) with Exelon subsidiary Commonwealth Edison (ComEd) under which "ComEd admitted it arranged jobs, vendor subcontracts, and monetary payments associated with those jobs and subcontracts, for various associates of a high-level elected official for the state of Illinois, to influence and reward the official's efforts to assist ComEd with respect to legislation concerning ComEd and its business."[961] ComEd paid a fine of US$200 million as a condition of the DPA. In November 2020, DOJ filed charges against two ComEd executives and two lobbyists/consultants:[962]

- Anne Pramaggiore, former CEO of ComEd from 2012–2018 and, from 2018–2019, vice president of Exelon's utilities division;
- John Hooker, former ComEd vice president of legislative and external affairs from 2009–2012, and, later, an outside lobbyist for the utility;
- Michael McClain, lobbyist and consultant to ComEd, and associate of House Speaker Madigan; and
- Jay Doherty, former contractor to ComEd from 2011–2019.

The charges involve jobs and contracts Exelon gave to associates of House Speaker Madigan, from 2011–2019. Pramagiorre and McClain each faced nine charges of conspiracy bribery and

957 - Vistra Corp., "Vistra Announces Acquisition of Energy Harbor", Press Release, 9 March 2023, see https://hub.vistracorp.com/vistra-announces-acquisition-of-energy-harbor/, accessed 16 August 2023.

958 - John Funk, "FirstEnergy Solutions filed for bankruptcy late Saturday", *Cleveland.com*, 1 April 2018, see https://www.cleveland.com/business/2018/03/firstenergy_solutions_bankrupt.html, accessed 4 August 2023.

959 - Phil Rogers, "Timeline: Federal Corruption Investigation Into Madigan, ComEd and Others", *NBC Chicago*, 3 March 2022, see https://www.nbcchicago.com/investigations/timeline-federal-corruption-investigation-into-madigan-comed-and-others/2774728/, accessed 5 September 2022.

960 - Kari Lyderson, "Illinois lobbying scandal rattles alliance backing state clean energy legislation", *Energy News Network*, 6 November 2019, see https://energynews.us/2019/11/06/illinois-lobbying-scandal-rattles-alliance-backing-state-clean-energy-legislation/, accessed 5 September 2022.

961 - U.S. Attorney's Office for the Northern District of Illinois, "Commonwealth Edison Agrees to Pay $200 Million to Resolve Federal Criminal Investigation Into Bribery Scheme: ComEd Admits Arranging Jobs and Contracts for Political Allies of High-Level State of Illinois Official", Press Release, U.S. Justice Department, 17 July 2020, see https://www.justice.gov/usao-ndil/pr/commonwealth-edison-agrees-pay-200-million-resolve-federal-criminal-investigation, accessed 5 September 2022.

962 - U.S. Attorney's Office for the Northern District of Illinois, "Former Commonwealth Edison Executives and Consultants Charged With Conspiring to Corruptly Influence and Reward State of Illinois Official", U.S. Justice Department, 18 November 2020, see https://www.justice.gov/usao-ndil/pr/former-commonwealth-edison-executives-and-consultants-charged-conspiring-corruptly, accessed 5 September 2022.

falsifying records. Hooker and Doherty were charged with six of the nine counts. Specifically, the investigation centered on Exelon's efforts to enact legislation in 2011 and 2016 worth billions of dollars in payments to its subsidiaries ComEd and Exelon Generation:

- **The 2011 Energy Infrastructure and Modernization Act** (**EIMA**) reformed Illinois's utility ratemaking process to allow ComEd largely to set its own delivery rates with less scrutiny by the Illinois Commerce Commission, through so-called "formula rates." A 2020-report by the Illinois Public Interest Research Group estimates ComEd collected more than US$4.7 billion in excess revenue from 2013–2019.[963]
- **The 2016 Future Energy Jobs Act** (**FEJA**), which extended EIMA's formula rates and included US$2.35 billion in "zero-emissions credits" over ten years for Exelon's Clinton and Quad Cities nuclear power plants. Exelon had blocked legislation to repair Illinois's renewable energy standard since 2014, demanding that the legislature enact subsidies for its nuclear power plants before fixing the renewable energy program. Madigan played the key role in blocking legislation Exelon opposed and in orchestrating the FEJA compromise.

On 2 May 2023, all four defendants were found guilty on all counts.[964] It was reported later that Exelon has paid the legal costs of Pramaggiore and Hooker, the former company executives.[965] Each of the defendants stated they intend to appeal. Pramaggiore's appeal, filed in July 2023, is based on an argument that the case actually proves her innocence, stating the evidence shows only that she accepted an elected official's input on the company's hiring decisions, not that she gave Madigan's associates jobs and contracts as part of a *quid pro quo*, in return for legislative favors he did for the company.[966] In a parallel matter, Pramaggiore is challenging a petition by the state's Attorney Registration & Disciplinary Commission to suspend her license to practice law, based on her conviction in the corruption case.[967]

The Justice Department investigation culminated in the indictment of former Illinois House Speaker Michael Madigan on 2 March 2022.[968] In October 2022, an additional conspiracy count was brought against him and McClain for their involvement in an alleged corruption

963 - Jeff St. John, "ComEd's Favorable Regulatory Treatment for Grid Investments Comes Under Fire", *GreenTech Media*, 1 December 2020, see https://www.greentechmedia.com/articles/read/comeds-long-running-state-regulatory-and-grid-investment-treatment-comes-under-fire, accessed 5 September 2022.

964 - U.S. Attorney's Office of the Northern District of Illinois, "Former Commonwealth Edison Executives and Associates Found Guilty of Conspiring To Influence and Reward Former Illinois House Speaker", Press Release, 2 May 2023, see https://www.justice.gov/usao-ndil/pr/former-commonwealth-edison-executives-and-associates-found-guilty-conspiring-influence; and Hannah Meisel, "UPDATED: 'ComEd Four' found guilty on all counts in bribery trial tied to ex-Speaker Madigan", *Capitol News Illinois*, 2 May 2023, see https://www.capitolnewsillinois.com/NEWS/updated-comed-four-found-guilty-on-all-counts-in-bribery-trial-tied-to-ex-speaker-madigan; both accessed 16 August 2023.

965 - Dave McKinney, "Exelon is paying the legal tab for two former executives convicted in ComEd bribery scheme", *WGLT/NPR*,16 May 2023, see https://www.wglt.org/illinois/2023-05-16/exelon-is-paying-the-legal-tab-for-two-former-executives-convicted-in-comed-bribery-scheme, accessed 2 August 2023.

966 - Steve Daniels, "Pramaggiore files full-throated, 77-page appeal of 'ComEd Four' verdict", *Crain's Chicago Business*, 10 July 2023, see https://www.chicagobusiness.com/politics/anne-pramaggiore-files-appeal-comed-four-verdict, accessed 2 August 2023.

967 - Dave McKinney, "Former ComEd CEO says her bribery conviction shouldn't lead to sanctions against her law license", *WBEZ Chicago*, 14 July 2023, see https://www.wbez.org/stories/convicted-comed-ceo-fights-to-keep-her-law-license/a3239fcc-7a2a-4283-83e3-0ee276b3d659, accessed 2 August 2023.

968 - U.S. Attorney's Office for the Northern District of Illinois, "Former Illinois Speaker of the House Indicted on Federal Racketeering and Bribery Charges in Connection With Alleged Corruption Schemes", Press Release, U.S. Justice Department, 2 March 2022, see https://www.justice.gov/usao-ndil/pr/former-illinois-speaker-house-indicted-federal-racketeering-and-bribery-charges, accessed 5 September 2022.

scheme involving AT&T Illinois.[969] Madigan held the Speakership of the Illinois House of Representatives for nearly 40 years and was long regarded as the most powerful political figure in the state. The 22-count indictment includes racketeering and bribery charges. At a January 2023 pre-trial status hearing, the judge set a trial date of 1 April 2024.[970]

Conclusion

The number of reactors and annual nuclear generation continued to decline in the United States in 2021–2022. With the closure of Palisades in May 2022, and grid connection of Vogtle-3 in March 2023, there were 93 commercial reactors operating as of mid-2023. Nuclear generation remained almost constant in 2022 but nuclear's share of commercial electricity generation fell from 19.6 percent to 18.2 percent, its lowest level since 1987. It also represents a drop of 4.3 percentage points from the nuclear sector's peak share of annual generation of 22.5 percent in 1995.[971]

While construction of Vogtle-3 and -4 has effectively been completed and the first of the two reactors has entered commercial operation, cost overruns and schedule delays have continued to plague the project. Total project costs have now topped US$31 billion, with Southern Company bearing an increasing share of the cost. The NRC approved first fuel loading for Unit 4, expected to start in late 2023 or Q1 2024. Further plans for construction of new reactors remain limited to three demonstration projects for new SMR and non-LWR designs, which are being sponsored by U.S. DOE. All three projects are planned to be online by 2030, but none have yet submitted license applications to the NRC. The projects have a combined generation capacity of 1,127 MW, effectively the equivalent of one of the new Vogtle reactors.

Since WNISR2022 was published, the new federal nuclear subsidies are still being implemented. The combination of direct federal subsidies for nuclear electricity generation, low-risk financing, and subsidies for producing hydrogen are providing significant incentives for second license extensions out to 80 years of operation. Yet the industry's prospects for growth remain stagnant, at best. The new federal nuclear production tax credit for existing reactors is set to expire in 2032, a mere three years after the 60-year operating licenses of the oldest reactors expire. The industry is exploring new business models, in an effort to exploit potentially more lucrative direct-consumer markets and federal hydrogen subsidies, while taking large blocks of nuclear generation off the grid. The viability of these business ventures—specifically, co-location at nuclear power plants of data centers and cryptocurrency mines and utility-scale hydrogen production—is not yet proven, but several corporations have signed contracts and initiated projects at nuclear reactor sites in 2022 and 2023.

969 - U.S. Attorney's Office for the Northern District of Illinois, "Superseding Federal Indictment Against Former Illinois Speaker of the House Adds Charge for Alleged Corruption Scheme Related to AT&T Illinois", Press Release, 14 October 2022, see https://www.justice.gov/usao-ndil/pr/superseding-federal-indictment-against-former-illinois-speaker-house-adds-charge, accessed 19 August 2023.

970 - Todd Feurer, "Former Speaker Mike Madigan's trial set for April 2024", *CBS News Chicago*, 9 January 2023, see https://www.cbsnews.com/chicago/news/former-speaker-mike-madigan-trial-april-2024/, accessed 2 August 2023.

971 - U.S.EIA, "Electricity data browser—Net generation for all sectors", U.S. Energy Information Administration, Undated, see https://www.eia.gov/electricity/data/browser/#/topic/0?agg=2,0,1&fuel=vtvv&geo=g&sec=g&linechart=ELEC.GEN.ALL-US-99.A~ELEC.GEN.COW-US-99.A~ELEC.GEN.NG-US-99.A~ELEC.GEN.NUC-US-99.A~ELEC.GEN.HYC-US-99.A~ELEC.GEN.WND-US-99.A~ELEC.GEN.TSN-US-99.A&columnchart=ELEC.GEN.ALL-US-99.A~ELEC.GEN.COW-US-99.A~ELEC.GEN.NG-US-99.A~ELEC.GEN.NUC-US-99.A~ELEC.GEN.HYC-US-99.A~ELEC.GEN.WND-US-99.A&map=ELEC.GEN.ALL-US-99.A&freq=A&ctype=linechart&ltype=pin&rtype=s&maptype=0&rse=0&pin=, accessed 21 July 2023; and IAEA-PRIS, "Nuclear electricity production and share from 1995 to 2022", 2023.

Three major corruption and fraud investigations involving both new reactors and nuclear subsidies continued developing in 2022–2023. Significant developments include the sentencing of former Ohio House Speaker Larry Householder to 20 years in the HB6 corruption investigation focusing on FirstEnergy, as well as the convictions of former Exelon executives and lobbyists in the Illinois corruption case.

FUKUSHIMA STATUS REPORT

OVERVIEW OF ONSITE AND OFFSITE CHALLENGES

Abstract

There has not been much progress in cleanup and decommissioning of the Fukushima Daiichi plant, in the past year and therefore since WNISR2022. One of the most controversial issues is the release of treated water, which still contains tritium and other radionuclides, despite the opposition from both local and international communities. The IAEA and a South Korean expert team reviewed the government plan, but this is unlikely to remove safety concerns of the release. Spent fuel removal from Unit 1 and 2 has not started and is currently planned for the Fiscal Year (FY) 2027–2028. One safety concern has been raised for Unit 1, as photos taken by investigating robots showed that the pedestal that supports the reactor pressure vessel was damaged and steel reinforcing rods were exposed, which could lead to the pedestal's collapse in case of a large earthquake. No significant progress has been made for debris removal. Offsite, the evacuation order was lifted for a part of Tomioka town and Iitate-village, where the area was designated as "special reconstruction zone" within the "difficult to return" area. As of 1 May 2023, according to the Fukushima Prefecture, 27,020 people were still away from home. Legal cases continue and several decisions at District Courts followed last year's Supreme Court decision to deny responsibility of the government, while ordering TEPCO to pay compensation.

Onsite Challenges[972]

Current Status of the Reactors

Throughout the year the temperatures of the Reactor Pressure Vessels (RPV) and the Primary Containment Vessels (PCV) were kept within the range of approx. 15–25 degrees Celsius through continuous reactor cooling by water injection. Data at monitoring posts at site boundaries showed radiation levels of 0.3–1.1 microSievert per hour (µSv/h) (29 March–25 April 2023). As the radiation levels inside the reactor buildings are still extremely high, it has not been possible to carry out measurements at all locations.

The removal of spent fuel from the cooling pools of Units 4 and 3 was completed in December 2014 and February 2021 respectively. For Unit 1, work to mount a large cover started in August 2021, and a temporary gantry is being installed. For Unit 2, work to remove the control room of the fuel-handling machine started from August 2022 and was completed in November 2022. The erection of a steel structure to support large equipment and machines for spent fuel removal started on 23 January 2023.

972 - This section, unless noted otherwise, is based on the following source: Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Outline of Decommissioning and Contaminated Water Management", Ministry of Economy, Trade and Industry (METI), Government of Japan, 27 April 2023, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/mp202304.pdf, accessed 21 June 2023.

Spent fuel removal from the pools is planned to start around FY 2027–2028 at both Unit 1 and Unit 2. Completion of spent fuel removal from all reactors is expected by the end of 2031, more than 20 years after the disaster began.

At Unit 1, investigation inside the pedestal by a remote-controlled robot (ROV-A2) was completed on 31 March 2023. During the investigation, it was confirmed that a lower section of concrete from inside the pedestal had melted and the bar arrangement was exposed. The images of the exposed steel reinforcement triggered concerns about the reactor's stability. Fukushima Governor Masao Uchibori urged Tokyo Electric Power Co (TEPCO) to "swiftly evaluate levels of earthquake resistance and provide information in a way prefectural residents can easily understand and relieve concern of the residents and people around the country".[973] The Nuclear Regulation Authority (NRA) instructed TEPCO to explore measures against possible release of radioactive materials if its PCV is damaged.[974] TEPCO will conduct a seismic assessment of the pedestal and is expected to report to NRA. No significant progress has been published regarding the retrieval of fuel debris.

Contaminated Water Management

Water is contaminated when underground water, including rainfall, passes through the reactor site and mixes with highly contaminated water in the basements of the reactor buildings. Some of that water is partially decontaminated and then used to cool the fuel debris inside the reactors. The generation of contaminated water has been gradually decreasing due to measures, such as pumping up water by sub-drains, the construction of land-side frozen walls, and rainwater-infiltration prevention measures, including repairing damaged portions of building roofs. As a result, the amount of contaminated water generation in 2022 declined to about 90 m^3/day—from 540 m^3/day in FY2014, when the government started considering countermeasures to limit the generation of contaminated water. The decline is also partially due to 20-percent lower rainfall in 2022 (1,192 mm) than in 2021 (1,470 mm).[975]

Part of the radioactive substances that contaminate the water are being removed by a multi-nuclide removal equipment called Advanced Liquid Processing Systems (ALPS). After the removal of most of the radioactive substances, except tritium, treated water is stored in tanks.

As of 24 August 2023, about 1.3 million m^3 of treated water were stored in 1,046 tanks. In addition, there are 24 storage tanks with water that has strontium-90 already removed below target levels, 12 storage tanks are being used for fresh water and one tank is being used for concentrated seawater on site.[976] Removal of strontium is done by cesium-absorption apparatus (KURION), secondary cesium-absorption apparatus (SARRY), and third

973 - Mari Yamaguchi, "New images from inside Fukushima reactor spark safety worry", *The Associated Press*, 5 April 2023, see https://apnews.com/article/japan-fukushima-nuclear-46f47feac0133640b9b72f7700b21f32, accessed 22 June 2023.

974 - *The Asahi Shimbun*, "鉄筋むき出し福島第一1号機　「東電は楽観的」と規制委が対策指示へ" ["NRA gave instruction to TEPCO to consider measures against possible damage, citing 'TEPCO is optimistic' regarding the damage shown at the Fukushima Daiichi Unit 1"], 25 May 2023 (in Japanese), see https://digital.asahi.com/articles/ASR5S6DZ2R5QULBH002.html, accessed 22 June 2023.

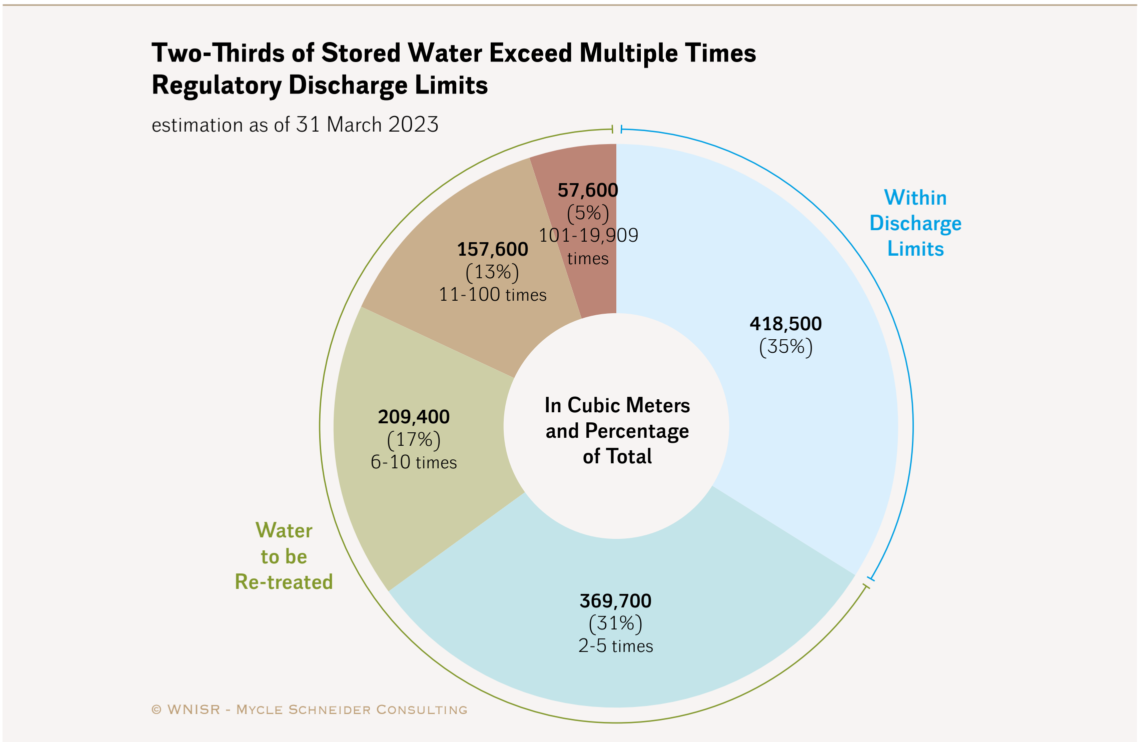
975 - METI, "Outline of Decommissioning and Contaminated Water Management", 27 April 2023, op. cit.

976 - TEPCO Holdings, "Treated Water Portal Site", as of 27 July 2023, see https://www.tepco.co.jp/en/decommission/progress/watertreatment/alps01/index-e.html, accessed 2 August 2023.

apparatus (SARRY II). Until 20 April 2023, approximately 712,000 m³ had been treated for strontium removal.

ALPS is supposed to reduce the concentration of radionuclides—except tritium—to levels below regulatory limits. However, due to malfunction and lower-than expected ALPS performance, as of 31 March 2023, of the 1.3 million m³ of treated water only about 35 percent (418,500 m³) satisfy regulatory standards and 65 percent (about 793,400 m³) need to be re-purified;[977] see Figure 53. The pre-service inspection of ALPS was completed and it went into operation on 18 April 2023.

Figure 53 • Percentages of Treated Water and Water to be Re-purified



Source: TEPCO Contaminated Water Portal Site, July 2023

Since the government decision on 13 April 2021 to discharge the "treated water" containing tritium and other radionuclides (whose concentrations would stay below regulatory standards), TEPCO has been preparing the discharge plan (see the detailed explanation in WNISR2022). Installing a pipe support for measurement and transfer facilities started on 4 August 2022 and the pre-service test launched on 16 January 2023. Drilling of the discharge tunnel (length is 1,031 m) was completed on 26 April 2023. On 26 June 2023, TEPCO announced that construction works for the sea tunnel to release "treated water" was completed, and once the inspection by NRA is completed which was scheduled to start from 28 June 2023, TEPCO is ready to start releasing "treated water".[978] The release of the first batch of 7,800 tons of

977 - METI, "Outline of Decommissioning and Contaminated Water Management", 27 April 2023, op. cit.

978 - *Fukushima News Web*, "福島第一原発 処理水海洋放出設備の工事すべて完了" ["Construction work for the release of treated water at Fukushima Daiichi is now completed"], *NHK*, 26 June 2023 (in Japanese), see https://www3.nhk.or.jp/lnews/fukushima/20230626/6050023049.html, accessed 27 June 2023.

contaminated water was diluted with seawater and released to the ocean between 24 August and 11 September 2023.[979]

Based on the Terms of Reference (TOR)[980] agreed between the IAEA and the Japanese Government, the IAEA established a Task Force and organized its work into three main components: 1) the assessment of protection and safety 2) regulatory activities and processes 3) independent sampling, data corroboration and analysis. The IAEA Task Force has published six reports on the water discharge plan, with Report 1 published on 29 April 2022 and Report 6 published on 31 May 2023.[981] On 4 July 2023, IAEA published its "Comprehensive Report on the Safety Review of the ALPS-Treated Water at the Fukushima Daiichi Nuclear Power Plant".[982] In the report, the IAEA concluded that "the approach to the discharge of ALPS treated water into the sea, and the associated activities by TEPCO, NRA, and the Government of Japan, are consistent with relevant international safety standards" and that "the discharge of the ALPS treated water, as currently planned by TEPCO, will have a negligible radiological impact on people and the environment."[983]

A team of South Korean experts also visited the Fukushima nuclear power plant to examine safety of ALPS-treated water and completed its examination on 24 May 2023. The delegation of 20 members included senior officials of South Korea's Nuclear Safety and Security Commission.[984] On 12 June 2023, South Korea's Oceans and Fisheries Ministry held the first of a series of nationwide briefings for the public "to explain seafood safety" in connection with the water-discharge plan.[985] On 19 June 2023, during a daily government briefing, Vice Oceans Minister Song Sang-keun said that the government will not use the term "nuclear waste water", saying "the term causes excessive and unnecessary concerns".[986] Meanwhile, on 22 June 2023, "seemingly determined to keep the Fukushima water issue alive" opposition leader Lee Jae-myung met with fishermen who are deeply concerned about the safety of the discharged water.[987] On 7 July 2023, following the release of IAEA's Comprehensive Report, Yoo Guk-hee, chairperson of South Korea's Nuclear Safety and Security Commission stated that "if the water release is carried out as planned, the discharge standard and target level (of radiation) would

979 - Ryo Sasaki and Keitaro Fukuchi, "First round of Fukushima water release completed", *The Asahi Shimbun*, 11 September 2023, see https://www.asahi.com/ajw/articles/15002709, accessed 21 September 2023.

980 - MOFA, "The handling of ALPS-treated water at TEPCO's Fukushima Daiichi Nuclear Power Station (Signing of a Terms of Reference (TOR) with IAEA", Press Release, Ministry of Foreign Affairs, Government of Japan, 8 July 2021, see https://www.mofa.go.jp/press/release/press6e_000310.html, accessed 23 June 2023.

981 - IAEA, "Fukushima Daiichi ALPS Treated Water Discharge-Reports", International Atomic Energy Agency, May 2023, see https://www.iaea.org/topics/response/fukushima-daiichi-nuclear-accident/fukushima-daiichi-alps-treated-water-discharge/reports, accessed 23 June 2023.

982 - IAEA, "IAEA Comprehensive Report on the Safety Review of the ALPS-Treated Water at the Fukushima Daiichi Nuclear Power Station", July 2023, see https://www.iaea.org/sites/default/files/iaea_comprehensive_alps_report.pdf, accessed 3 September 2023.

983 - Ibidem.

984 - *NHK World News*, "S. Korean experts complete Fukushima nuclear plant examination", *Japan Broadcasting Corporation*, 24 May 2023.

985 - *The Mainichi Shimbun*, "S. Korea begins briefings to ease anxiety over Fukushima water", 13 June 2023, see https://mainichi.jp/english/articles/20230613/p2g/00m/0in/051000c, accessed 23 June 2023.

986 - *Yonhap*, "Gov't calls for refraining from referring to Fukushima water as 'nuclear waste water'", *The Korea Times*, 19 June 2023, see https://www.koreatimes.co.kr/www/nation/2023/06/120_353236.html, accessed 23 June 2023.

987 - Jung Min-ho, "Opposition leader meets fishermen amid Fukushima worries", *The Korea Times*, 22 June 2023, see https://www.koreatimes.co.kr/www/nation/2023/06/113_353496.html, accessed 23 June 2023.

be consistent with international standards."[988] While the Government through Bang Moon-kuy, Minister for Government Policy Coordination of South Korea, said "we have confirmed concentration of radioactive material meets standards for ocean discharge", it indicated that the ban on food and seafood from the Fukushima region would be maintained. Yoo Guk-hee, head of South Korea's Nuclear Safety and Security Commission, said its expert on the panel did not have specific concerns.[989] Still, both fishermen and consumers are worried about the impact of water release from the Fukushima nuclear plant, and the largest fisheries market in South Korea started radioactive monitoring of the fish to allay consumers' concerns.[990]

Referring to recent South Korean government's dispatching technical experts to Japan, Japanese government officials called for a science-based dialogue with China, expressing concern that the Chinese government described the treated water as "contaminated" water. Meanwhile, Chinese Foreign Ministry spokesman Wang Wenbin said that Japan has so far failed to prove the planned water discharge is safe and harmless.[991] It was reported that a Chinese expert in the group declared himself disappointed with the "hasty" report.[992]

Still both domestic and international opposition persists. On 22 June 2023, the head of Japan's national fisheries cooperatives released a statement opposing the planned discharge of treated water. Masanobu Sakamoto, president of National Federation of Fisheries Cooperatives said, "We cannot support the government's stance that an ocean release is the only solution" and "whether to release the water into the sea or not is a government decision, and in that case we want the government to fully take responsibility".[993]

The Secretary General of the Pacific Island Forum (PIF) stated on 4 January 2023, that "we must take the time to closely examine whether current international standards are adequate to handle the unprecedented case of Fukushima Daiichi."[994] The PIF also established its own independent expert panel, and a memo from the panel was reported to complain that Japan has not been very transparent about the full impacts of the release.[995]

988 - Kim Tong-Hyung, "South Korea vouches for safety of plans to release Fukushima wastewater but citizens' fears persist", *The Associated Press*, 7 July 2023, see https://apnews.com/article/south-korea-japan-nuclear-fukushima-wastewater-f8af2517be24786e2e3a94de35f8cd56, accessed 18 July 2023.

989 - Hyunsu Yim, Soo-hyang Choi and Jack Kim, "South Korea says Japan's water release plan meets standards", *Reuters*, 7 July 2023, see https://www.reuters.com/world/asia-pacific/south-korea-says-respects-iaea-review-japans-fukushima-wastewater-plan-2023-07-07/, accessed 17 July 2023.

990 - Daewoung Kim and Jimin Jung, "South Korean market tests fish, seafood to dispel Fukushima radiation fears", *Reuters*, 7 July 2023, see https://www.reuters.com/business/environment/south-korean-market-tests-fish-seafood-dispel-fukushima-radiation-fears-2023-07-06/, accessed 3 September 2023.

991 - *The Mainichi Shimbun*, "Japan seeks scientific dialogue with China on Fukushima water plan", 14 June 2023, see https://mainichi.jp/english/articles/20230613/p2g/00m/0na/060000c, accessed 23 June 2023.

992 - Hyunsu Yim, Soo-hyang Choi and Jack Kim, "South Korea says Japan's water release plan meets standards", *Reuters*, 2023, op. cit.

993 - Mari Yamaguchi, "Japanese Fisheries Head Oppose a Plan to Pump Treated Radioactive Water from Fukushima Into the Sea", *The Associated Press*, 23 June 2023, see https://apnews.com/article/japan-nuclear-fukushima-water-discharge-fisheries-44faa2dc4165f49c4dbaf35c53ee10a4, accessed 17 July 2023.

994 - Heny Puna, "Japan must work with the Pacific to find a solution to the Fukushima water release issue- otherwise we face disaster", Secretary General, Pacific Island Forum, as published in *The Guardian*, 4 January 2023, see https://www.theguardian.com/commentisfree/2023/jan/04/japan-must-work-with-the-pacific-to-find-a-solution-to-the-fukushima-water-release-issue-otherwise-we-face-disaster, accessed 30 September 2023.

995 - *ABC*, "Pacific Islands Forum and Japan deliver differing statements on plans to dump nuclear waste water in ocean", *Australia Broadcasting Company*, 9 February 2023, see https://www.abc.net.au/pacific/programs/pacificbeat/pacific-islands-forum-nuclear-wastewater-negotiations/101950446, accessed 23 June 2023.

According to the latest paper by the expert panel published on 12 June 2023, its main findings are: [996]

1) A presumption that TEPCO's plan would comply in principle with all guidelines does not appear to include the transboundary implications of IAEA's guidance in its General Safety Guide No. 8 (GSG-8) that requires that benefits outweigh the harms for individuals and societies.

2) The Panel recommended an option that would avoid transboundary impacts, in conformity with GSG-8. That option is to treat the water in the ALPS system as now proposed by TEPCO and then to use it to make concrete with little potential for human contact.

One of the panel experts, Dr. Robert Richmond, director of the Kewalo Marine Laboratory of the University of Hawaii, said that "it is a trans-boundary and trans-generational event". While he stated that he does not believe "the release would irreparably destroy the Pacific Ocean", he considers "it doesn't mean we should not be concerned".[997]

On 24 August 2023, TEPCO announced it had started discharging treated and diluted water from the Fukushima Daiichi nuclear plant, and it was reported that the first round of the release would happen over 17 days involving a total of 7,800 tons of treated water, the first step of a process that will take at least 30 years.[998] According to TEPCO's plan, it will start by discharging water with a low concentration of tritium (190 Bq/liter after dilution), and the total amount of tritium to be discharged during FY 2023 will be about 5 trillion Bq. TEPCO also reported that the sum of ratios of the concentration of each radionuclide (excluding tritium) to be discharged first has been measured to be 0.28 (regulatory requirement is "less than 1.0").[999]

Responding to the beginning of the release China has reiterated its opposition to the activity and announced the postponement of a visit to China by the head of the Japanese political party Komeito, Natuo Yamaguchi, that had been scheduled to start on 28 August 2023.[1000] China also announced that it banned imports of all seafood products from Japan shortly after the start of the discharging of treated water.[1001] The Japanese government said that it will carefully monitor Chinese moves before deciding whether to file a complaint with the World Trade Organization (WTO). While some members of the ruling party suggest that Japan should file a complaint with the WTO, others say Tokyo should avoid any confrontation with China.[1002]

996 - Arjun Makhijani, Ferenc Dalnoki Veress, et al., "Minimizing Harm: the concrete option for solving the accumulation of radioactive contaminated water at the Fukushima Daiichi Nuclear Power Plant site—A paper prepared by the Independent Expert Panel to the Pacific Islands Forum", 12 June 2023, see https://cafethorium.whoi.edu/wp-content/uploads/sites/9/2023/06/Concrete-paper-Final-2023-06-12-v-2.pdf, accessed 3 September 2023.

997 - Lesly M.M. Blume, "Japan is poised to release nuclear waste water into the Pacific. How worried should we be?", *National Geographic*, 25 May 2023, see https://www.nationalgeographic.com/premium/article/fukushima-japan-nuclear-wastewater-pacific-ocean, accessed 23 June 2023.

998 - *NHK*, "Japan begins releasing treated water from Fukushima Daiichi Plant", *Japan Broadcasting Corporation*, 24 August 2023, see https://www3.nhk.or.jp/nhkworld/en/news/backstories/2670/, accessed 3 September 2023.

999 - TEPCO Holdings, "Information about the Discharge of Multi-nuclide removal Equipment Treated Water into the Sea", 22 August 2023, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2023/pdf/230822e0101.pdf, accessed 3 September 2023

1000 - *NHK*, "China reiterates claims over treated water release after reports of harassment", 28 August 2023.

1001 - *Kyodo News*, "China bans Japan seafood after water release, rallies in Hong Kong, Seoul", 24 August 2023, see https://english.kyodonews.net/news/2023/08/7d810c62b8eb-china-to-boost-radiation-monitoring-after-fukushima-water-release.html, accessed 30 September 2023.

1002 - *NHK*, "Japan weighing response to China's seafood import ban", 31 August 2023.

Worker Exposure Trend

TEPCO has published data on worker exposure every month since the Fukushima accidents began. According to the latest report for FY2022 (April 2022–March 2023),[1003] average cumulative dose rate for TEPCO employees (1,412 employees) was 0.80 mSv, while the average dose rate for contractors (9,902 contractors) was 2.34 mSv, resulting in a total average of 2.15 mSv which is about the same level as last year (2.51 mSv). The maximum estimated dose for a TEPCO employee was 11.85 mSv (13.10 mSv for FY2021), while that for contractors was 17.60 mSv (17.46 mSv for FY2021). As illustrated above, contractors typically receive about two to three times higher radiation doses than TEPCO employees.

Offsite Challenges

Current Status of Evacuation

As of 1 May 2023, 27,020 (32,404 as of March 2022) residents of Fukushima Prefecture are still living as evacuees (6,147 are living within the prefecture, 20,868 are living outside the prefecture). The number of evacuees decreased from 164,865 in May 2011.[1004]

In 2022, evacuation orders were lifted for the first time for some parts of the so-called "difficult to return area" (where annual estimated radiation levels are higher than 50 mSv per year), which are designated as "reconstruction and revitalization areas". Those areas receive special government funding for reconstruction. Evacuation orders were lifted for parts of Kuzuo village on 12 June 2022, followed by parts of Okuma town on 30 June 2022, and Futaba on 30 August 2022, the latest such measure to date.[1005] As a result, the share of evacuation zones in the total Fukushima Prefecture land area shrank from about 12 percent to 2.3 percent as of August 2022. While in some towns most residents have returned, such as Hirono-cho, where 90 percent of the original population settled back as of January 2023, in others only very few have made the move, e.g. only 4.2 percent and 1.1 percent of the population returned to Okuma and Futaba towns respectively.[1006]

1003 - TEPCO Holdings, "Evaluation of the exposure dose of workers engaged in radiation work at the Fukushima Daiichi Nuclear Power Station", 28 April 2023, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/exposure/pdf/2023/exposure_20230428-e.pdf, accessed 24 June 2023.

1004 - Disaster Countermeasures Headquarters, "Heisei 23 nen Tohoku Chiho Taiheiyou Jishin ni yoru Higai Jokyo Sokuho, #1792" ["Current status of damages caused by 2011 Tohoku East Pacific Earthquake—Report1792"], Fukushima Prefecture, 12 June 2023 (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/life/694344_1961228_misc.pdf, accessed 24 June 2023.

1005 - *NHK*, "【解説】東日本大震災・原発事故「帰還困難区域」―ゼロからわかる福島のいま　第１１回" ["Great East Earthquake/Nuclear Power Accident "Difficult to Return Area": Understand current situation of Fukushima from zero"], 21 February 2023 (in Japanese), see https://www.nhk.or.jp/fukushima/lreport/article/000/31/, accessed 3 September 2023.

1006 - Fukushima Prefecture Reconstruction Headquarter, "Fukko/Saisei no Ayumi ~Fukushima no Ima~" ["Progress for Reconstruction/Revitalization—Current status of Fukushima, 10th edition"], 27 March 2023 (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/568386.pdf, accessed 24 June 2023.

Food Contamination

Inspections for food contamination continue,[1007] with a total of 36,309 samples analyzed in FY2022 (41,361 in FY2021) of which 135 from 10 prefectures exceeded the radionuclide concentration limit[1008] (157 in FY2021), according to national data published by the Ministry of Health, Labor and Welfare. Of these 135 contaminated samples (all from area-based control, except 11), 68 were from wild animal meat (found in four prefectures), 62 from wild plants and mushrooms (in nine prefectures) and four of dried fruit and mushrooms (from two prefectures). The nationwide number of analyzed items "drastically decreased in FY2020, due to the conclusion of all-cattle-monitoring in four prefectures, i.e. Iwate, Miyagi, Fukushima and Tochigi",[1009] and has been on a steady decline since.

Although sample analyses in Fukushima Prefecture was cut by more than half in one year, the number of identified items that exceeded safety standards increased in FY2022 with 51 out of 5,963 (0.85 percent) compared to FY2021, when there were 42 out of 14,053 (0.3 percent). The number even doubled compared to FY2020, when there were 25 out of 15,539 (0.16 percent) samples exceeding legal limits. The decision to significantly reduce monitoring despite a growing number of contaminated samples is perplexing. In fact, the prefecture carrying out the most sampling in Japan was not Fukushima anymore which fell behind Miyagi and Iwate. By contrast, Miyagi Prefecture—the second prefecture with the most samples with excessive contamination levels (33 in FY2021 and 45 in FY2022)—continuously increased the scope of testing over the past years, from 4,568 in FY2020 to 6,332 in FY2021 and finally 8,554 in FY2022.

Fukushima Prefecture still accounted for the highest number of contaminated items in FY2022. Out of the 51 samples with contamination levels exceeding limits, 45 were wild game meat. While the absolute number of items found to be improper for consumption is low, only 196 analyses on wild animal meat had been conducted in Fukushima Prefecture (six more than the previous year), meaning that about 23 percent (45) of these animal samples were contaminated beyond legal limits (15 percent in 2021). That is a remarkably high ratio that raises the question why there is not a mandatory testing program for certain categories of wild game meat.

By comparison, Miyagi Prefecture undertook twice as many tests (398) on wild animal meat compared to Fukushima Prefecture—finding that 2.2 percent (9) contained excess radionuclide concentration—yet conducted 29 less than the previous year.[1010] The various paradoxes, discrepancy in implementation over time, and the relatively low number of analyzed samples throughout Japan do not allow for comprehensive data.

1007 - MHLW, "Sum up of radionuclide test results reported in FY 2022", Ministry of Health, Labor and Welfare, Government of Japan, April 2023, see https://www.mhlw.go.jp/english/topics/2011eq/dl/Sum%20up_March_2023.pdf, accessed 3 September 2023.

1008 - The standard value established by the Ministry of Health, Labor and Welfare: The level of radioactive cesium is 100 Bq/kg for food, 10 Bq/kg for drinking water, 50 Bq/kg for milk, and 50 Bq/kg for infant food.

1009 - Pharmaceutical Safety and Environmental Health Bureau, "Radionuclides in foods—Current situation and protective measures", Ministry of Health, Labour and Welfare, Government of Japan, see https://www.mhlw.go.jp/english/topics/2011eq/dl/food-130926_1.pdf, 2022, accessed 20 July 2023.

1010 - MHLW, "Sum up of radionuclide test results reported in FY2022", Ministry of Health, Labour and Welfare, Government of Japan, as of 31 March 2023, see https://www.mhlw.go.jp/english/topics/2011eq/dl/Sum%20up_March_2023.pdf; and MHLW, "Sum up of radionuclide test results reported in FY2021", as of 31 March 2022, see https://www.mhlw.go.jp/english/topics/2011eq/dl/Sum_up_March_2022.pdf; both accessed 18 July 2023.

As of 1 July 2023, still 12 countries and regions maintained restrictions on food imports from Japan. China, Hong Kong, and Macao suspended all imports of food of Fukushima Prefecture origin. South Korea and Taiwan partially restricted food imports. Six countries and regions (French Polynesia, Iceland, Lichtenstein, Norway, Russia and Switzerland) allow food imports from Japan only with verified inspection records. This was also the case of the European Union until 13 July 2023, when the European Commission lifted the implemented measures.[1011] A further 43 countries lifted all restrictions on food imports from Japan over the years.[1012]

Decontamination and Contaminated Soil

The decontamination work for the Special Decontamination Area of Fukushima Prefecture under the direct control of the national government[1013] was completed in March 2018, and the decontamination work for relevant municipalities including the rest of Fukushima Prefecture[1014] was completed in March 2017 (this decontamination work did not include the Difficult-to-Return Zones). However, the reality is that decontamination has only been conducted over a small percentage of the overall contaminated land area.[1015]

The biggest issue is what to do with the huge amount of contaminated soil shipped to interim storage sites. The government designated a total of 1,600 ha of land as "interim storage site", and as of May 2022, 80.4 percent of the area (1,286 ha) had been "contracted" for the establishment of storage facilities.[1016] As of the end of March 2023, four out of a total of ten storage facilities were "completed" (i.e. stored amount reached full capacity), and about 88 percent of total storage capacity is now filled with decontaminated soil (see Table 14).[1017]

1011 - European Commission, "EU-Japan Summit: Commission lifts the Fukushima restrictions on food imports", Press Release, 13 July 2023, see https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3781, accessed 18 July 2023.

1012 - Fukushima Fukko Joho Portal site, "福島県産食品の輸入規制の状況" ["Status of import restrictions of food originated from Fukushima Prefecture"], 1 August 2022, Fukushima Reconstruction Information Portal Site (in Japanese), see https://www.pref.fukushima.lg.jp/site/portal/ps-overseasrestriction040726.html, accessed 24 June 2023.

The 43 countries are: Canada, Myanmar, Serbia, Chile, Mexico, Peru, Guinea, New Zealand, Columbia, Malaysia, Ecuador, Vietnam, Iraq, Australia, Thailand, Bolivia, India, Kuwait, Nepal, Iran, Mauritius, Qatar, Ukraine, Pakistan, Saudi Arabia, Argentina, Turkey, New Caledonia, Brazil, Oman, Bahrain, Republic of Congo, Brunei, Philippines, Morocco, Egypt, United Arab Emirates, Lebanon, Israel, Singapore, the United States, the United Kingdom (excluding Northern Ireland) and Indonesia.

1013 - A high dose area within a 20km radius of the power plant, located around the difficult-to-return zone.

1014 - It covers all eight prefectures, including Fukushima Prefecture, except for the Special Decontamination Area managed by the government.

1015 - Aaron Clark, "Decade after Fukushima disaster, Greenpeace sees cleanup failure", *Bloomberg*, as published by *The Japan Times*, 4 March 2021, see https://www.japantimes.co.jp/news/2021/03/04/national/fukushima-greenpeace-radiation-health-3-11/; and Greenpeace East Asia, "Fukushima Daiichi 2011-2021: The decontamination myth and a decade of human rights violations", March 2021, see https://www.greenpeace.org/static/planet4-japan-stateless/2021/03/ff71ab0b-finalfukushima2011-2020_web.pdf; both accessed 19 August 2021.

1016 - Ministry of the Environment, "中間貯蔵施設の概要／進捗状況—中間貯蔵施設の概要" ["Overview of Interim Storage Facilities"], Government of Japan, March 2023 (in Japanese), see http://josen.env.go.jp/chukanchozou/about/#section03, accessed 26 June 2023.

1017 - Ministry of the Environment, "中間貯蔵施設事業の状況等について" ["Current Status of Interim Storage Facilities"], Government of Japan, March 2023 (in Japanese), see http://josen.env.go.jp/chukanchozou/action/safety_commission/pdf/safety_commission_02_230328.pdf, accessed 26 June 2023.

Table 14 · Status of Interim Storage Facilities for Decontaminated Soil

Area	Okuma-1	Okuma-2	Okuma-3	Okuma-4	Okuma-5	Futaba-1	Futaba-2	Futaba-3	Total
Number of facilities	1	2	1	1	1	2	1	-	10
Storage Capacity (10^6 m^3)	1.0	3.3	2.1	1.6	2.0	1.4	0.9	0.8	13.1 (100%)
Stored amount (10^6 m^3)	1.07	2.92	1.48	1.56	2.03	0.90	0.93	0.66	11.55 (88.2%)
Status of facility	Completed (December 2022)	One completed (May 2022)	Operating	Operating	Operating	One completed	Completed (October 2022)	Operating	

Source: Ministry of the Environment, March 2023.[1018]

In order to reduce the final volume of decontaminated soil to be disposed of, in 2016, the Government published a plan to "reuse" such soil which is considered "safe" for certain purposes.[1019] Demonstration projects have been conducted in Minami-soma and Iidate Village, Fukushima Prefecture.[1020] The Ministry of the Environment planned to start a demonstration project, outside of Fukushima prefecture for the first time, at Saitama prefecture's "Environmental Research and Training Center" by the end of FY2022, but now decided to postpone the project due to opposition from the local public. The Mayor of Tokorozawa city (which is located in the Saitama prefecture), has expressed disapproval of the plan, as the majority of the local neighborhood associations opposed the plan.[1021]

LEGAL CASES, RESIDENT HEALTH, COMPENSATION

After the Supreme Court decision in 2022, (see the detailed explanation in WNISR2022 – Fukushima Status Report), several lower court decisions in 2023 also dismissed government responsibility.[1022]

- On 10 March 2023, the Sendai High Court reversed an earlier decision from the lower court which had ruled that the accident could have been prevented if the government had taken appropriate measures. By denying the claim, the High Court dismissed the responsibility

1018 - Ministry of the Environment, "中間貯蔵施設事業の状況等について" ["Current Status of Interim Storage Facilities"], Government of Japan, March 2023 (in Japanese), see http://josen.env.go.jp/chukanchozou/action/safety_commission/pdf/safety_commission_02_230328.pdf, accessed 26 June 2023.

1019 - Ministry of the Environment, "除去土壌の再生利用について" ["Regarding the Reuse of Decontaminated Soil"], Government of Japan, Undated (in Japanese), see http://josen.env.go.jp/chukanchozou/facility/recycling/, accessed 26 June 2023.

1020 - Ministry of the Environment, "What Does 'Recycling of Removed Soil' Mean?", Government of Japan, October 2022, see http://josen.env.go.jp/chukanchozou/material/pdf/removed-soil_recycling-en_2205.pdf, accessed 19 July 2023.

1021 - *NHK*, "Reuse of decontaminated soil Demonstration project outside Fukushima Prefecture Postponed to start before the end of fiscal year", as published on *Teller Report*, 25 February 2023, see https://www.tellerreport.com/life/2023-02-24-reuse-of-decontaminated-soil-demonstration-project-outside-of-fukushima-prefecture-postponed-to-start-before-the-end-of-the-fiscal-year.B1DNJoUoj.html, accessed 26 June 2023.

1022 - *Fukushima Min-yu Shimbun*, "Genpatsu Jiko, Saikosai Hitei Hanketsu kara 1 nen, Genkoku 'Kozoku Sosho de Kutsugaeshitai" ["One year after the Supreme Court Decision on Fukushima Nuclear Accident, Groups want to sue again to reverse the decision"], 17 June 2023.

of the government in the Fukushima accidents. The Court ordered TEPCO however to pay some compensation for the residents in Iwaki-city, judging that they were not informed of the evacuation order in a timely manner. The plaintiffs plan to appeal the ruling before the Supreme Court.[1023]

- On 14 March 2023, the Okayama District Court also dismissed government liability for the accidents, following last year's Supreme Court decision. In this case, 105 citizens who evacuated from Fukushima to Okayama Prefecture, sued the government and TEPCO for compensation. Instead, the Court ordered TEPCO to pay a small compensation of a total of 30 million yen (~US$214,000).[1024]
- On 15 March 2023, the Fukushima District Court ruled out government responsibility for the Fukushima accidents in two cases. One case was brought by a group of 587 citizens of Odaka-district of Minami-Soma city, and the other case was filed by a group of 313 citizens of Kashima-district of Minami-Soma city. The Court rejected the credibility of a long-term seismic assessment prepared by a governmentally-appointed panel in 2002 which had pointed to the possibility of an earthquake followed by a tsunami hitting the region, and rejected the claim the accidents could have been prevented if the government had taken measures accordingly. Instead, the Court ordered TEPCO to pay a total of 1,529 million yen (~US$11 million) to the 502 citizens of Odaka-district, and 29.6 million yen (~US$211,000) to be distributed between 269 citizens of Kashima-district.[1025]

Meanwhile, three senior TEPCO executives at the time of the accident, Tsunehisa Katsumata, Ichiro Takeguro, and Sake Muto, on 18 January 2023,[1026] were acquitted again by the Tokyo District Court following a second trial.[1027]

On 24 June 2023, Sapporo High Court dismissed the case brought by a person who claimed that his three cancers were caused by his occupation during the Fukushima Daiichi accidents. He first filed the case to the Labor Standards Oversight Division of Tomioka town of Fukushima Prefecture, but his claim was declined by the office. The Sapporo Court said it would not be possible to link the cause of his cancers to the work at the Fukushima nuclear plant as he had smoking and drinking habits.[1028]

1023 - *Fukushima News Web*, "原発集団訴訟 国の責任を認めず 仙台高等裁判所で判決" ["Group Litigation on Fukushima accident, The Sendai High Court dismissed Government responsibility"], *NHK,* 10 March 2023 (in Japanese), see https://www3.nhk.or.jp/lnews/fukushima/20230310/6050022006.html, accessed 26 June 2023.

1024 - *NHK Okayama News Web*, "原発事故で福島から岡山に避難 国の責任認めず 岡山地裁" ["Evacuated from Fukushima to Okayama due to the Nuclear Accident, Local Court dismissed government responsibility"], 14 March 2023 (in Japanese), see https://www3.nhk.or.jp/lnews/okayama/20230314/4020016013.html, accessed 26 June 2023.

1025 - N. Takiguchi and N. Otsuki, "原告「納得できない」福島地裁、国の責任否定 南相馬—の原発2訴訟" ["Plantiff were dissatisfied with the decision by the Fukushima District Court, denying government responsibility, 2 cases braught by citizens of Minami Souma"], *The Asahi Shimbun*, 15 March 2023 (in Japanese), see https://www.asahi.com/articles/ASR3G6TK7R3GUGTB003.html, accessed 26 June 2023.

1026 - *NHK News*, "【詳細】東電旧経営陣3人に無罪判決 東京高裁 判決のポイント" ["Key Points of Court Decisions by the Tokyo District Court Acquitting Three Former Senior Executives of TEPCO"], 18 January 2023 (in Japanese), see https://www3.nhk.or.jp/news/html/20230118/k10013952821000.html, accessed 26 June 2023.

1027 - *The Mainichi Shimbun*, "元原発作業員の請求、高裁が棄却／北海道" ["Claim by former worker at nuclear plant was denied by Higher court, Hokkaido"], 24 June 2023 (in Japanese), see https://mainichi.jp/articles/20230624/ddl/k01/040/130000c, accessed 26 June 2023.

1028 - Ibidem.

As of June 2023, the total compensation amount paid out by TEPCO is 10,817 billion yen (~US$$_{2023}$77.5 billion).[1029]

CONCLUSION

The main onsite and offsite challenges of the Fukushima disaster remain the same they have been throughout the past 12 years. One of the most controversial issues onsite is the decision made by the Government to release “treated water” containing tritium and other radionuclides into the sea. While the IAEA and the South Korean government sent experts to review the plan, both domestic and international opposition remains strong. For offsite issues, legal challenges against both the government and TEPCO continue. While lower court decisions were sometimes in favor of plaintiffs, the higher court decisions tend to follow the decisions made by the Supreme Court, which denied any liability of the government. Still, the courts ordered TEPCO to pay symbolic amounts of compensation to plaintiffs. Although three senior executives were acquitted in the criminal case, legal responsibility of TEPCO in civil cases seemed unavoidable.

1029 - TEPCO, “原子力損害賠償のご請求・お支払い等実績” [“Current Status of Compensation Claimed and Paid So Far”], Tokyo Electric Power Co Holdings, 23 June 2023 (in Japanese), see https://www.tepco.co.jp/fukushima_hq/compensation/images/jisseki01-j.pdf, accessed 26 June 2023.

DECOMMISSIONING STATUS REPORT

INTRODUCTION

In mid-2023, 212 nuclear power reactors were closed, corresponding to, for the first time, over 100 GW of permanently retired capacity. This compares with 407 operating reactors and 31 units in Long-Term Outage; thus, almost one third of the reactors connected to the grid in the past 70 years have been retired.

Decommissioning nuclear power plants is an important, and often overlooked, element of the nuclear electricity system. Defueling, deconstruction, and dismantling—summarized by the term decommissioning—are the final steps in the operational cycle of a nuclear power plant (excluding waste management and disposal). The process is technically complex and poses major challenges in terms of long-term planning, implementation, and financing. Decommissioning was, in the first decades of the nuclear age, hardly considered in the reactor design, and the costs for decommissioning at the end of the lifetime of a reactor were usually discounted away, and thus, subsequently, largely ignored. However, as a growing number of nuclear facilities either reach the end of their operational lifetimes or have already been closed, the challenges of reactor decommissioning are increasingly attracting stakeholder and public attention.

Elements of National Decommissioning Policies

When analyzing decommissioning policies, one needs to distinguish between the process itself (in the sense of the actual implementation), and the financing. The technical procedure can generally be divided into three main stages, which are briefly described hereunder (for more details, see WNISR2018).

- The **warm-up stage** comprises the post-operational stage and the dismantling of systems that are not needed for the decommissioning process. In addition, the dismantling of higher contaminated system parts begins, including the defueling of the reactor which is crucial for any further undertakings and means removing the spent fuel from the reactor core and the spent fuel pools.
- The **hot-zone stage** comprises the dismantling activities in the hot zone, i.e. dismantling of highly contaminated or activated parts, e.g. the reactor pressure vessel (RPV) and its internals (RVI), the biological shield.
- The **ease-off stage** comprises the removal of operating systems as well as decontamination of the buildings. Ideally, this stage ends with the demolition of the buildings and the release of the reactor site as a greenfield site for unrestricted use but the release as a brownfield site is allowed in some countries, which means that the buildings can also be further used, for nuclear or other purposes.

This technical procedure can begin after varying amounts of time following nuclear power plant closure. This depends on the strategy the operator chooses. The options include:

- *immediate dismantling*, that is characterized by a rapid start of decommissioning activities after reactor closure,
- *deferred dismantling*, where reactors are placed into Long-term Enclosure (LTE) for several decades to allow for radiation levels to decline before decommissioning begins, and
- *entombment*, characterized by LTE (50 years or more) that can in some cases become permanent.
- Most countries have adopted variations of these strategies, although some, like France or Germany, have placed restrictions on which strategy may be applied.[1030]

With respect to financing, five main approaches are observable: Public budget, external segregated fund, internal non-segregated fund, internal segregated fund, and surety methods such as guarantees (for more details, see WNISR2018).[1031]

GLOBAL OVERVIEW

Decommissioning Worldwide

As of 1 July 2023, a worldwide total of 212 reactors, corresponding to 105.3 GW of capacity, have been closed. Since WNISR2022, eight additional reactors (8 GW) have been closed: three in Germany, two each in the U.K. and Belgium and one in Taiwan.

Of the total number of closed units, 61 percent are in Europe (105 in Western Europe and 25 in Central and Eastern Europe), with around one fifth of the total in North America (47) and one sixth in Asia (35).

Almost four in five or 168 reactors used one of these three technologies:

- Pressurized Water Reactors (PWRs) with 69 units or 33 percent,
- Boiling Water Reactors (BWRs) with 55 units or 26 percent, and
- Gas-Cooled Reactors (GCRs) with 44 units or 21 percent, the majority (33 units) of which are located in the U.K.

Table 15 provides an overview of the closed reactors worldwide. The table also includes the number of defueled decommissioned reactors, and those that are released from regulatory supervision, i.e., where a full greenfield situation has been re-established. The Decommissioning Status Report does not cover all smaller research reactors that were not connected to the grid and may have been closed in some countries but rather focusses on higher capacity research and commercial reactors that generated electricity.

1030 - Tim Scherwath, Ben Wealer and Roman Mendelevitch, "Nuclear decommissioning after the German Nuclear Phase-Out an integrated view on new regulations and nuclear logistics", Energy Policy, Vol. 137, February 2020, see https://www.sciencedirect.com/science/article/abs/pii/S0301421519307128, accessed 24 July 2023; and ASN, "ASN Report on the state of nuclear safety and radiation protection in France in 2020", Autorité de Sûreté Nucléaire/French Nuclear Safety Authority, August 2021, see https://www.french-nuclear-safety.fr/asn-informs/publications/asn-s-annual-reports/asn-report-on-the-state-of-nuclear-safety-and-radiation-protection-in-france-in-2020, accessed 7 April 2022; also U.S. NRC, "Decommissioning of Nuclear Power Reactors", Draft Regulatory Guide DG-1347, Revision 1, United States Nuclear Regulatory Commission, February 2022, see https://www.nrc.gov/docs/ML2134/ML21347A080.pdf, accessed 4 July 2022.

1031 - Alexander Wimmers, Rebekka Bärenbold et al., "Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production", Data Documentation 104, DIW Berlin, Deutsches Institut für Wirtschaftsforschung/German Institute for Economic Research, January 2023, see https://www.diw.de/documents/publikationen/73/diw_01.c.864222.de/diw_datadoc_2023-104.pdf, accessed 26 January 2023.

Table 15 · Overview of Reactor Decommissioning Worldwide (as of 1 July 2023)

Country	Closed Reactor	Post-Operational Stage[(a)]	Decommissioning Status					
			Warm-up (of which Defueled)	Hot Zone	Ease-off	LTE	Completed (of which Released)	Completed Share (of which Released)
U.S.[(b)]	41	1	5 (5)	5	2	11	17 (7)	41% (17%)
U.K.	36		21 (13)	9	0	6	0	0%
Germany	36	4	8 (5)	10	9	1	4 (3)	11% (8%)
Japan	27		26 (5)	0	0	0	1 (1)	4% (4%)
France	14		4 (1)	2	0	8	0	0%
Russia	10	1	2 (1)	0	0	7	0	0%
Sweden	7		3 (1)	4	0	0	0	0%
Canada	6		1 (1)	0	0	6	0	0%
Bulgaria	4		4	0	0	0	0	0%
Italy	4		3 (2)	1	0	0	0	0%
Taiwan	4	2	2	0	0	0	0	0%
Ukraine	4		0	0	0	4	0	0%
Slovakia	3		1 (1)	0	2	0	0	0%
Spain	3		1	0	1	1	0	0%
Belgium	3		2	0	1	0	0	0%
Lithuania	2		2 (2)	0	0	0	0	0%
South Korea	2		2	0	0	0	0	0%
Armenia	1		0	0	0	1	0	0%
India	1		1 (1)	0	0	0	0	0%
Kazakhstan	1		0	0	0	1	0	0%
Netherlands	1		0	0	0	1	0	0%
Pakistan	1	1	0	0	0	0	0	0%
Switzerland	1		1	0	0	0	0	0%
Total	**212**	**9**	**89 (38)**	**31**	**15**	**46**	**22 (11)**	**10% (5%)**

Sources: Various, compiled by WNISR, 2023

Notes:

(a) - Many recently closed reactors have not officially begun with decommissioning and are in a so-called "post-operational stage". These are Brokdorf Emsland, Grohnde and Isar-2 in Germany, Kuosheng-1 and -2 in Taiwan, Kursk-1 in Russia, Kanupp-1 in Pakistan, and Palisades in the U.S.

(b) Previous WNISR editions had classified Vermont Yankee in the U.S. as being the in the warm-up-stage when in fact hot-zone tasks were ongoing. The reactor has since moved to the ease-off stage.

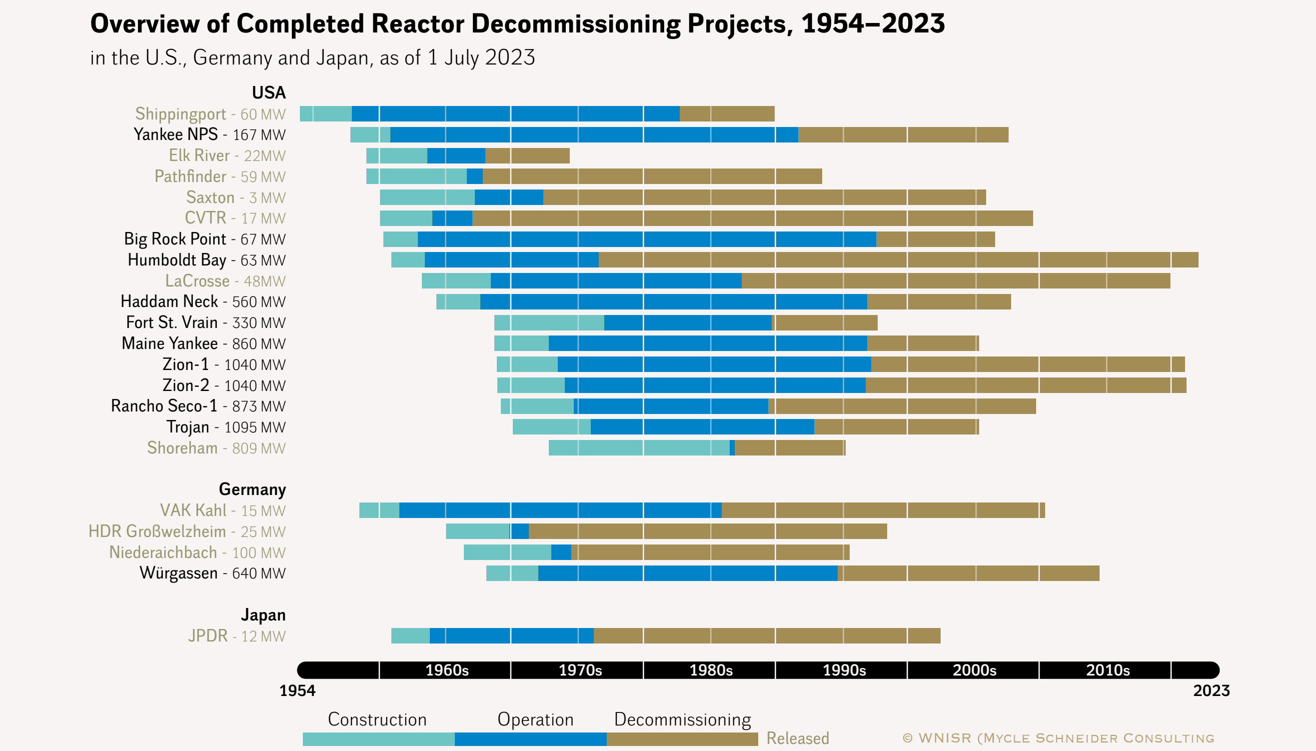
Decommissioning plays an important and increasing role in nuclear politics, both in timing and production process, and the financing thereof. The number of facilities that will be affected will increase significantly: Assuming a 40-year average lifetime, a further 138 reactors will close by 2030 (reactors connected to the grid between 1983 and 1990); and an additional 149 will be closed by 2063. This does not even account for the 120 reactors that have already been operating for 41 years or more, an additional 31 reactors in Long-term Outage (LTO), and the 58 reactors under construction as of mid-2023.

Overview of Reactors with Completed Decommissioning

As of mid-2023, 190 units are globally awaiting or in various stages of decommissioning, eight more than one year earlier. Since WNISR2021, no additional reactor has completed the technical decommissioning process.

Of the 22 decommissioned reactors, only 11 have been released from regulatory oversight (see Figure 54), of which eight have been returned to a greenfield status. Since WNISR2022, one additional reactor, LaCrosse, a 48-MW BWR located in the U.S., had its license terminated, but will not be returned to a greenfield status as an interim waste storage facility remains onsite (see United States Case Study). The average duration of the decommissioning process, independent of the chosen strategy, is around 21 years, with a very high variance: the minimum being six years for the 22-MW Elk River plant, and the maximum at 45 years for the 63-MW reactor at Humboldt Bay, both in the U.S.

Figure 54 · Overview of Completed Reactor Decommissioning Projects, 1954–2023



Sources: Various, compiled by WNISR, 2023

Only three countries amongst the 23 with closed power reactors have completed the technical decommissioning process of at least one reactor: the United States (17 units), Germany (4), and Japan (1). Some of the reactors amongst the most rapidly decommissioned are located in the U.S. In Germany, the HDR (Heißdampfreaktor, a superheated-steam reactor) Großwelzheim was only on the grid for one year, but decommissioning lasted well over 20 years. The German Würgassen reactor has de facto completed the technical decommissioning process but, legally, cannot be released from regulatory control as buildings are being used for interim storage of wastes.[1032] In Japan, the only reactor to be decommissioned was a small 10-MW demonstration plant (JPDR), whereas none of the large commercial reactors has yet been decommissioned.[1033] Figure 54 provides the timelines of the 22 reactors that have completed the decommissioning process.

Overview of Ongoing Reactor Decommissioning

This section contains a brief overview of the decommissioning status in the countries that are not analyzed in the subsequent case studies.

Following a partnership agreement with the European Union, the **Armenian** Medzamor nuclear power plant is to be completely closed as soon as possible due to safety concerns because the plant "cannot be upgraded to fully meet internationally accepted safety standards".[1034] Unit 1 had already been closed in 1989 after an earthquake. A pilot decommissioning project by Rosatom subsidiary Nukem Technologies, German state-owned company EWN and U.S.-Australian WorleyParsons is currently underway.[1035] WNISR considers the reactor to be in LTE until actual dismantling begins. Unit 2 is scheduled to operate until 2026.[1036] Recent reports suggest that another ten-year lifetime extension is being considered.[1037]

In **Belgium**, one reactor, the prototype 10 MW reactor BR-3 in Mol, closed in 1987, is currently undergoing decommissioning. With the completion of the dismantlement of the biological shield in 2022,[1038] the reactor entered the ease-off stage and is used as a lead-and-learn site for future decommissioning projects.[1039] As of early October 2023, the Belgian legislation still calls for the closure of all seven operational reactors at Doel and Tihange in 2025 and estimates

1032 - Ines Bredberg, et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2018", Bfe-KE-04/19, Bundesamt für kerntechnische Entsorgungssicherheit/Federal Office for the Safety of Nuclear Waste Management (in German), 2019, see https://doris.bfs.de/jspui/bitstream/urn:nbn:de:0221-2019081919007/3/BfE-KE-04_19_Statusbericht_zur_Kernenergienutzung_2018_Rev.pdf, accessed 20 July 2023.

1033 - JAIF, "Current Status of Nuclear Power Plants in Japan – as of February, 7 2023", Japan Atomic Industrial Forum, 7 February 2023, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2023/02/jp-npps-operation20230207_en.pdf, accessed 30 August 2023.

1034 - High Representative of the Union for Foreign Affairs and Security Policy, "Partnership Implementation Report on Armenia", Joint Staff Working Document, European Commission, 16 December 2020, see https://www.eeas.europa.eu/sites/default/files/armenia_partnership_implementation_report_2020.pdf, accessed 8 June 2022.

1035 - Nukem Technologies, "Pilot Decommissioning Project at Metsamor Nuclear Power Plant", 2022, see https://www.nukemtechnologies.de/en/projects/am/pilot-decommissioning-project-at-metsamor-nuclear-power-plant, accessed 8 June 2022.

1036 - *WNN*, "Long-term safety of Armenian plant reviewed by IAEA", *World Nuclear News*, 8 November 2021, see https://www.world-nuclear-news.org/Articles/Long-term-safety-of-Armenian-plant-reviewed-by-IAE, accessed 8 June 2022.

1037 - *The Armenian Mirror-Spectator*, "Armenia Considers Nuclear Options", 15 June 2023, see https://mirrorspectator.com/2023/06/15/armenia-considers-nuclear-options/, accessed 16 June 2023.

1038 - SCK CEN, "Pioneering work with demolition plan and international expertise", Studiecentrum voor Kernenergie/Centre d'étude de l'énergie nucléaire/Belgian Nuclear Energy Research Center, 2022, see https://www.sckcen.be/en/about-sck-cen/annual-reports/highlights-2022/highlights-2022-dismantling-and-waste/pioneering-work-demolition-plan-and-international-expertise, accessed 30 August 2023.

1039 - Wouter Broeckx, Sven Boden et al., "Decommissioning of the BR3 biological shield: How a proper data analysis facilitates the D&D process", 15 September 2021, presented at "DEM 2021 International Conference on Decommissioning Challenges: Industrial Reality, Lessons Learned and Prospects", Société française d'énergie nucléaire/French Society for Nuclear Power, European Nuclear Society, 13–15 September 2021, see https://publications.sckcen.be/portal/en/publications/decommissioning-of-the-br3-biological-shield-how-a-proper-data-analysis-facilitates-the-dd-process(b1c1354d-e0ac-47d2-9784-595b60c12f0b).html; and SCK CEN, "Dismantling and decontamination", Undated, see https://www.sckcen.be/en/expertises/technology/dismantling-and-decontamination; both accessed 8 June 2022.

decommissioning costs of €18 billion (US$$_{2021}$18.82 billion).[1040] In March 2022, however, the Belgian government decided to initiate negotiations with the operator to extend operational lifetimes of Tihange-3 and Doel-4 until 2035,[1041] and a provisional agreement was reached in January 2023 that set out both reactors to close in 2025 for refurbishment work and then restart in November 2026.[1042] Doel-3 closed on 23 September 2022 and is currently in the warm-up stage as defueling is underway.[1043] In July 2022, the Belgian government asked operator Engie whether the planned closure of Tihange-2 could be postponed by several months to the end of March 2023. Engie declined stating the request had come at too short a notice and consequentially, Tihange-2 was closed on 31 January 2023[1044] (see Belgium Focus). Engie plans internal reactor part dismantling to begin in 2026 at both reactors while defueling began right after closure.[1045]

At all four units of the Kozloduy nuclear plant in **Bulgaria**, turbine hall dismantling was completed in 2019.[1046] Actual nuclear decommissioning began in 2022, when the first circuit was deactivated at all four reactors and first components in contaminated areas were dismantled.[1047]

Rajasthan-1 in **India**—placed in LTO (Long-Term Outage) status since 2004 and since 2014 considered as closed by WNISR—has been completely defueled and is currently "maintained under dry preservation".[1048] WNISR considers the reactor in the warm-up phase.

Decommissioning has been underway since 1998 at Aktau BN-350, a sodium-cooled fast reactor in **Kazakhstan**. The reactor will be transferred into an LTE status over a span of ten years. The plan is to then keep the reactor in LTE for 50 years, after which dismantling is to begin.[1049] Spent fuel was removed with financial support from the U.S. government from 1999

1040 - Andreas Kockartz, "Der Rückbau der belgischen Kernkraftwerke kostet mindestens 18 Mia. €", *Belga*, as published by *vrt* (in German) June 2021, see https://www.vrt.be/vrtnws/de/2021/06/30/der-rueckbau-der-belgischen-kernkraftwerke-kostet-mindestens-18/, accessed 10 June 2022.

1041 - *Belga*, "Prolongation du nucléaire : le conseil des ministres avalise la prolongation de deux réacteurs au-delà de 2025", as published on *RTBF.be*, 1 April 2022 (in French), see https://www.rtbf.be/article/prolongation-du-nucleaire-le-conseil-des-ministres-avalise-la-prolongation-de-deux-reacteurs-au-dela-de-2025-10967487, accessed 22 June 2022.

1042 - Geert De Clercq and Charlotte van Campenhout, "Belgium to extend life of two nuclear reactors by 10 years", *Reuters*, 9 January 2023, see https://www.reuters.com/business/energy/belgium-extend-life-two-nuclear-reactors-by-10-years-2023-01-09/, accessed 16 June 2023.

1043 - *WNN*, "First Belgian power reactor shut down", *World Nuclear News*, 27 September 2022, see https://www.world-nuclear-news.org/Articles/First-Belgian-power-reactor-shut-down, accessed 11 October 2022.

1044 - *WNN*, "Second Belgian reactor enters retirement", *World Nuclear News*, 31 January 2023, see https://www.world-nuclear-news.org/Articles/Second-Belgian-reactor-enters-retirement, accessed 7 February 2023.

1045 - ENGIE, "Shutdown of Doel 3 and Tihange 2", ENGIE Electrabel, Undated, see https://nuclear.engie-electrabel.be/en/nuclear-energy/shutdown-our-nuclear-power-plants/shutdown-doel-3-and-tihange-2, accessed 16 June 2023.

1046 - SERAW, "Decommissioning of nuclear installations", State Enterprise Radioactive Waste, 2022, see https://tinyurl.com/DPRAODecom, accessed 24 July 2022.

1047 - *3E News*, "Bulgaria reported to the EC its progress on the decommissioning of the small units of the Kozloduy NPP", 15 November 2022, see https://3e-news.net/en/a/view/38832/bulgaria-reported-to-the-ec-its-progress-on-the-decommissioning-of-the-small-units-of-the-kozloduy-npp, accessed 1 June 2023.

1048 - NPCIL, "Rawatbhata Rajasthan Site", Nuclear Power Corporation of India Limited, Department of Atomic Energy, 2017, see https://www.npcil.nic.in/content/501_1_rawatbhatarajasthansite.aspx, accessed 16 June 2023.

1049 - Kamen Kraev, "Rosatom To Help With BN-350 Fast Neutron Reactor Decommissioning", *NucNet*, 29 July 2020, see https://www.nucnet.org/news/rosatom-to-help-with-bn-350-fast-neutron-reactor-decommissioning-7-3-2020, accessed 24 July 2023.

to 2016 with several joint projects conducted over the years.[1050] In 2020, total project costs were estimated at KZT125 billion (US$330 million), paid for via a fee on local residents' electricity bills.[1051]

In **the Netherlands**, the 55-MW reactor Dodewaard was placed in LTE in 2005 with the aim to return the site to greenfield status.[1052] Owner Netherlands Electricity Administration Office (NEA) plans to begin dismantling the plant in 2045. NEA estimates the cost at around €270 million (US$295.7 million).[1053] It became public in 2023 that NEA, after having paid out dividends totaling €1.5 billion (US$1.63 billion) to its shareholders Vattenfall, EPZ, Uniper and Engie, had a mere €162 million (US$177.5 million) left in the bank, prompting the Dutch government to take over financial liability for Dodewaard and infusing the cash fund with additional €100 million (US$109.5 million). According to a judgement by the court of Gelderland from 2017, the Dutch government had attempted to reprimand the shareholders for the payment of the dividends, but this turned out to be "legally impossible".[1054]

In August 2021, **Pakistan** closed its first reactor KANUPP-1, a 90-MW CANDU reactor that had been operating for 50 years.[1055] A decommissioning license to implement a deferred dismantling strategy was granted on 27 June 2022, but it was not reported whether actual work has begun.[1056] Until progress is reported, WNISR classifies the reactor to be in the post-operational phase.

Slovakia's decommissioning efforts are advancing, with reactor pressure vessels having been removed in late 2021 at Bohunice-1 and -2 by Westinghouse[1057] and, by end of July 2022, reactor internals at both units having been fully dismantled. This puts both units into the ease-off stage. The remaining systems and equipment are to be dismantled by 2025, and buildings are to be demolished by 2027 to allow for the reuse of the site.[1058] The project, for which operator JAVYS is being hailed for its development of "innovative digital tools" that are "being adopted by decommissioning projects around the world", is estimated to cost

1050 - R. W. Schaefer, R. T. Klann et al., "Criticality Safety Issues in the Disposition of BN-350 Spent Fuel", Argonne National Laboratory, National Nuclear Center of the Republic of Kaakhstan and Kazakhstan Atomic Energy Committee, presented at the ANS 4. Embedded Topical Meeting on DOE Spent Nuclear Fuel and Fissile Material Management, 4-8 June 2000; and *NEI Magazine*, "Local residents pay for decommissioning of Kazakhstan's BN-350 reactor", 27 February 2020, see https://www.neimagazine.com/news/newslocal-residents-pay-for-decommissioning-of-kazakhstans-bn-350-reactor-7796914, accessed 30 August 2023.

1051 - *NEI Magazine*, "Local Residents Pay for Decommissioning of Kazakhstan's BN-350 Reactor", 2020, op. cit.

1052 - OECD/NEA, "Radioactive Waste Management Programmes in OECD/NEA Member Countries—Netherlands", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, 2008, see https://www.oecd-nea.org/jcms/pl_33758/netherlands-profile-web, accessed 8 June 2022.

1053 - *NL Times*, "Shareholder payouts meant gov't had to push €100 mil. into breaking down nuclear plant", 30 May 2023, see https://nltimes.nl/2023/05/30/shareholder-payouts-meant-govt-push-eu100-mil-breaking-nuclear-plant, accessed 16 June 2023.

1054 - Orla McDonald, "Energiebedrijven trokken €1,5 mrd uit kerncentrale Dodewaard", *Het Financieele Dagblad*, 29 May 2023 (in Dutch), see https://fd.nl/bedrijfsleven/1477103/energiebedrijven-trokken-1-5-mrd-uit-kerncentrale-dodewaard, accessed 30 August 2023.

1055 - PAEC, "Nuclear Power: A Viable Option for Electricity Generation", Pakistan Atomic Energy Commission, 2022, see https://paec.gov.pk/nuclearpower/, accessed 8 June 2022.

1056 - PNRA, "Nuclear Power Plants", Pakistan Nuclear Regulatory Authority, 2023, see https://www.pnra.org/npps.html, accessed 16 June 2023.

1057 - *WNN*, "Pressure vessel segmented at Bohunice", *World Nuclear News*, 29 November 2021, see https://www.world-nuclear-news.org/Articles/Pressure-vessel-segmented-at-Bohunice; and *WNN*, "Westinghouse signs Bohunice V1 dismantling contract", 28 September 2017, see https://www.world-nuclear-news.org/Articles/Westinghouse-signs-Bohunice-V1-dismantling-contrac; both accessed 8 June 2022.

1058 - *WNN*, "Bohunice V1 reactors fully dismantled", *World Nuclear News*, 29 July 2022, see https://www.world-nuclear-news.org/Articles/Bohunice-reactors-fully-dismantled-in-decommissioi, accessed 16 June 2023.

around €1.24 billion (US$1.36 billion), funded by the European Bank for Reconstruction and Development and the E.U.[1059] Bohunice A1, a 93-MW heavy water GCR-type reactor, began decommissioning in 1999. All fuel has been removed from the site since 2009. The dismantlement of external structures and of low to medium level contaminated components is scheduled to be completed by 2025, after which the reactor is planned to advance to the hot-zone stage. Decommissioning is expected to be completed by 2033.[1060]

Sweden's latest reactor closure occurred in 2020 when Unit 1 of the Ringhals nuclear power plant was permanently taken off the grid. Both reactors at the site are currently in the warm-up stage. Westinghouse was to begin actual decommissioning work in the third quarter of 2022[1061] but owner Vattenfall pushed the beginning of dismantling work to the fall of 2023.[1062] At Ringhals-2, a consortium led by Nuvia, a subsidiary of French construction giant Vinci, was tasked with dismantling primary loop and reactor cooling pumps, to be carried out between February and August 2024.[1063]

The first Swedish reactor, Ågesta, was closed in 1974 and subsequently defueled.[1064] The plant was being used as a training facility until 2020, when Westinghouse was tasked with its dismantling.[1065] Operations at Ågesta included tests of new in-situ dismantling technologies for control rods with remote cutting tools.[1066]

Reactors at Barsebäck and Oskarshamn are currently in the hot-zone stage. At Barsebäck-1, the reactor pressure vessel was successfully dismantled in late 2021.[1067] At Barsebäck-2, the vessel was dismantled by Westinghouse in 2018.[1068] Reactor internals at Oskarshamn were dismantled for both reactors in 2019 by GE Hitachi Nuclear Energy.[1069] In 2020, Spanish company GD Energy Services was contracted for four years to further continue decommissioning at

1059 - Michael Madsen, "Slovakia Sets Global Example for Nuclear Power Plant Decommissioning", *IAEA Bulletin*, Vol. 64-1, April 2023, see https://www.iaea.org/bulletin/slovakia-sets-global-example-for-nuclear-power-plant-decommissioning, accessed 16 June 2023.

1060 - JAVYS, "Annual Report 2022", Jadrová a vyraďovacia spoločnos, March 2023, see https://www.javys.sk/data/web/dokumenty/vyrocne-spravy/javys-annual-report-2022-final-r.pdf, accessed 30 August 2023.

1061 - Vattenfall, "Vattenfall Annual and Sustainability Report 2021", March 2022, p.43, see https://mb.cision.com/Main/865/3534511/1555469.pdf; and *WNN*, "Ringhals reactors to be dismantled by Westinghouse", *World Nuclear News*, August 2019, see https://www.world-nuclear-news.org/Articles/Ringhals-reactors-to-be-dismantled-by-Westinghouse; both accessed 8 June 2022.

1062 - Vattenfall, "Avveckling Ringhals 1 och 2—Produktion", Undated (in Swedish), see https://group.vattenfall.com/se/var-verksamhet/ringhals/produktion/avveckling-ringhals-1-och-2, accessed 16 June 2023.

1063 - Freyssinet, "Decommissioning of Ringhals Nuclear power plant Unit 2 in Sweden", Press Release, 3 April 2023, see https://www.freyssinet.com/ringhals-nuclear-plant-sweden/, accessed 16 June 2023.

1064 - Vattenfall, "Ågesta power plant", Undated, see https://history.vattenfall.com/stories/agesta-power-plant, accessed 8 June 2022.

1065 - Westinghouse Electric Company, "Westinghouse Wins Environmental Contract with Vattenfall to Dismantle Ågesta Nuclear Plant", Press Release, 17 December 2020, see https://info.westinghousenuclear.com/news/westinghouse-wins-environmental-contract-with-vattenfall-to-dismantle-%C3%A5gesta-nuclear-plant, accessed 8 June 2022.

1066 - *Nuclear Engineering International*, "Ågesta nuclear power plant: Managing control rods for decommissioning", as published by *NS ENERGY*, 21 March 2022, see https://www.nsenergybusiness.com/features/agesta-nuclear-power-plant-managing-control-rods-for-decommissioning/, accessed 16 June 2023.

1067 - *WNN*, "Uniper completes dismantling of two RPVs in parallel", *World Nuclear News*, 23 March 2022, see https://www.world-nuclear-news.org/Articles/Uniper-completes-dismantling-of-two-RPVs-in-parall, accessed 8 June 2022.

1068 - *NEI Magazine*, "Decommissioning progress at Sweden's Barsebäck", *Nuclear Engineering International*, 19 March 2018, see https://www.neimagazine.com/news/newsdecommissioning-progress-at-swedens-barsebck-6087602, accessed 8 June 2022.

1069 - *WNN*, "Dismantling of Oskarshamn reactor internals completed", *World Nuclear News*, 19 December 2019, see https://world-nuclear-news.org/Articles/Dismantling-of-Oskarshamn-reactor-internals-comple, accessed 8 June 2022.

Oskarshamn and Barsebäck.[1070] Decommissioning work is scheduled to be completed by 2028 at both plants.[1071]

Switzerland has some decommissioning experience, having completed technical decommissioning at the research reactor at Lucens in 2004.[1072] Decommissioning of the commercial reactor at Mühleberg began shortly after its closure in 2019. The reactor itself has been defueled but transfer of spent fuel to an interim dry-storage facility will only be completed in 2024 as many fuel assemblies currently remain in pool storage on site. Hot-zone works are expected to last from 2025 to 2030 and plans indicate decommissioning is planned to be completed in 2034.[1073]

In **Taiwan**, reactors are being progressively closed under the national nuclear phaseout policy. Kuosheng-2 marks the latest closure in March 2023, finalizing the closure of the two-unit nuclear plant.[1074] Mid-2021, operator Taipower submitted the application to close the last two remaining operating reactors at the Maanshan nuclear power plant by 2025.[1075] Decommissioning of all Taiwanese reactors (including the two Maanshan units) is to be completed by 2043[1076], but at Chinshan-1 (taken off the grid in 2014 and officially closed in 2018 when its license expired) delays occurred already in 2018 due to belated approval of onsite dry storage facilities.[1077] Whether work is proceeding as set out in a 2019-plan that sees defueling to be completed and hot-zone works to begin in 2026, remains unclear.[1078] As of 2023, defueling was hindered by lack of access to a dry spent fuel facility with fuel remaining in the reactor core as wet storage pools have reached their full capacity. According to Taiwan's Atomic Energy Council, the development of a dry storage facility is being blocked by "local government and antinuclear organizations".[1079]

1070 - Foro Nuclear, "GDES reaches a milestone with decommissioning work at Barsebäck, the Swedish nuclear power plant", Press Release, 11 April 2022, see https://www.foronuclear.org/en/updates/news/gdes-reaches-a-milestone-with-decomissioning-o-swedish-npp-barseback/, accessed 16 June 2023.

1071 - Kristina Gillin, "Sweden prepares for a decade of nuclear decommissioning", *NS Energy*, 27 February 2020, see https://www.nsenergybusiness.com/news/nuclear-decommissioning-sweden/:~:text=Sweden%20is%20preparing%20to%20dismantle,sites%20over%20the%20coming%20years.&text=Nuclear%20power%20plants%20are%20preparing,of%20nuclear%20decommissioning%20in%20Sweden.&text=By%20the%20end%20of%202020,permanently%20shut%20down%20for%20decommissioning, accessed 8 June 2022.

1072 - ENSI, "Serie Lucens: Der Rückbau eines Pionierwerks", Eidgenössisches Nuklearsicherheitsinspektorat/Swiss Federal Nuclear Safety Inspectorate (in German),14 June 2012, see https://www.ensi.ch/de/2012/06/14/serie-lucens-der-rueckbau-eines-pionierwerks/, accessed 8 June 2022.

1073 - BKW, "Die Stilllegung des Kernkraftwerks Mühleberg", Undated (in German), see https://www.bkw.ch/de/energie/energieproduktion/stilllegung-kernkraftwerk-muehleberg, accessed 16 June 2023.

1074 - *WNN*, "Taiwanese reactor enters retirement", *World Nuclear News*, 14 March 2023, see https://www.world-nuclear-news.org/Articles/Taiwanese-reactor-enters-retirement, accessed 16 March 2023.

1075 - *WNN*, "Taipower applies to deommission Maanshan plant", *World Nuclear News*, 27 July 2021, see https://www.world-nuclear-news.org/Articles/Taipower-applies-to-decommission-Maanshan-plant, accessed 9 June 2022.

1076 - *NEI Magazine*, "Taipower applies to close down Maanshan NPP", 29 July 2021, see https://www.neimagazine.com/news/newstaipower-applies-to-close-down-maanshan-npp-8946136/, accessed 9 June 2022.

1077 - Lin Chia-nan, "AEC approves Taipower's Jinshan decommission plan", *Taipei Times*, 13 July 2019, see https://www.taipeitimes.com/News/taiwan/archives/2019/07/13/2003718586, accessed 24 July 2023.

1078 - Chang-Lin Hsieh and Yu-Kai Huang, "Plans for Chinshan", *Nuclear Engineering International*, 6 March 2019, see https://www.neimagazine.com/features/featureplans-for-chinshan-7025241/, accessed 16 June 2023.

1079 - Chin-Cheng Huang, "Carbon Neutrality and Current Status of Nuclear Power in Taiwan", Director, Mechanical & System Engineering Program, Institute of Nuclear Energy Research, Atomic Energy Council, 13 April 2023, presented at the 14th International Workshop on the Integrity of Nuclear Components, Asian Society for Integrity of Nuclear Components, 12–14 April 2023, see http://www.jwes.or.jp/mt/asinc014/pdf/ks_taiwan%20cch.pdf, accessed 30 August 2023.

In **Ukraine**, decommissioning work at all four reactors of the Chernobyl plant is continuing after Russian forces, that had occupied the plant for several weeks in 2022, returned control of the site back to Ukrainian personnel.[1080] During the occupation of the site, decommissioning licenses that had been revoked by Ukrainian authorities were reinstated in August 2022, allowing work to continue.[1081] Chernobyl 1–3 are currently being defueled[1082] and are to be placed into LTE following the chosen deferred dismantling strategy.[1083] Repairing support infrastructure, damaged by the Russian forces, will likely cause some delay and an initial estimate from the European Bank for Reconstruction and Development (EBRD) expects additional costs of at least €100 million (US$$_{2022}$111 million).[1084] The New Safe Confinement for Unit 4 was completed in 2016.[1085]

Decommissioning in Selected Countries

This section provides an update of decommissioning development reviews in eleven major countries: Canada, France, Germany, Italy, Japan, Lithuania, Russia, South Korea, Spain, the U.K., and the U.S. As in previous years, decommissioning projects encountered delays as well as cost increases. This section provides information on developments since WNISR2022. WNISR2023 counted 159 reactors currently in the different decommissioning stages or awaiting decommissioning in these 11 countries; this represents 84 percent of all closed reactors, excluding completed projects.

Of these, six reactors are currently in the post-operational phase, 75 are in the warm-up stage, 27 reactors in the hot-zone stage, and 12 are in the ease-off stage. The early nuclear states U.K., France, Russia, and Canada are yet to fully decommission a single reactor. Initially, the U.K. and Russia put all their closed reactors into Long-Term Enclosure (LTE), postponing decommissioning into the future. The U.K. has since changed its strategy and has begun earlier decommissioning for its extensive GCR fleet. WNISR counts a total of 46 reactors in LTE worldwide, 39 located in the selection of eleven countries.

Figure 55 reflects the slow progress that the global decommissioning industry is making. Over the past four years, few reactors have moved forward in their decommissioning processes. Most notably, the U.K. has changed its initial LTE approach for its GCR Magnox fleet to a

1080 - NEA, "Ukraine: Current status of nuclear power installations", Nuclear Energy Agency, 7 June 2023, Updated 16 June 2023, see https://www.oecd-nea.org/jcms/pl_66130/ukraine-current-status-of-nuclear-power-installations, accessed 16 June 2023.

1081 - Lewis Tyler, "Decommissioning resumes at Chernobyl nuclear plant", *Demolition & Recycling International*, 31 August 2022, see https://www.demolitionandrecycling.media/news/decommissioning-resumes-at-chernobyl-nuclear-plant/8022984.article, accessed 16 June 2023.

1082 - EBRD, "Decommissioning the Chernobyl Nuclear Power Plant", European Bank for Reconstruction and Development, Undated, see https://www.ebrd.com/what-we-do/sectors/nuclear-safety/chernobyl-decommissioning-power-plant.html, accessed 9 June 2022; and ChNPP, "ChNPP resumes RAW processing and disposal activities", Chornobyl NPP, 24 August 2022, see https://chnpp.gov.ua/en/infocenter/news/6079-chnpp-resumes-raw-processing-and-disposal-activities, accessed 25 July 2023.

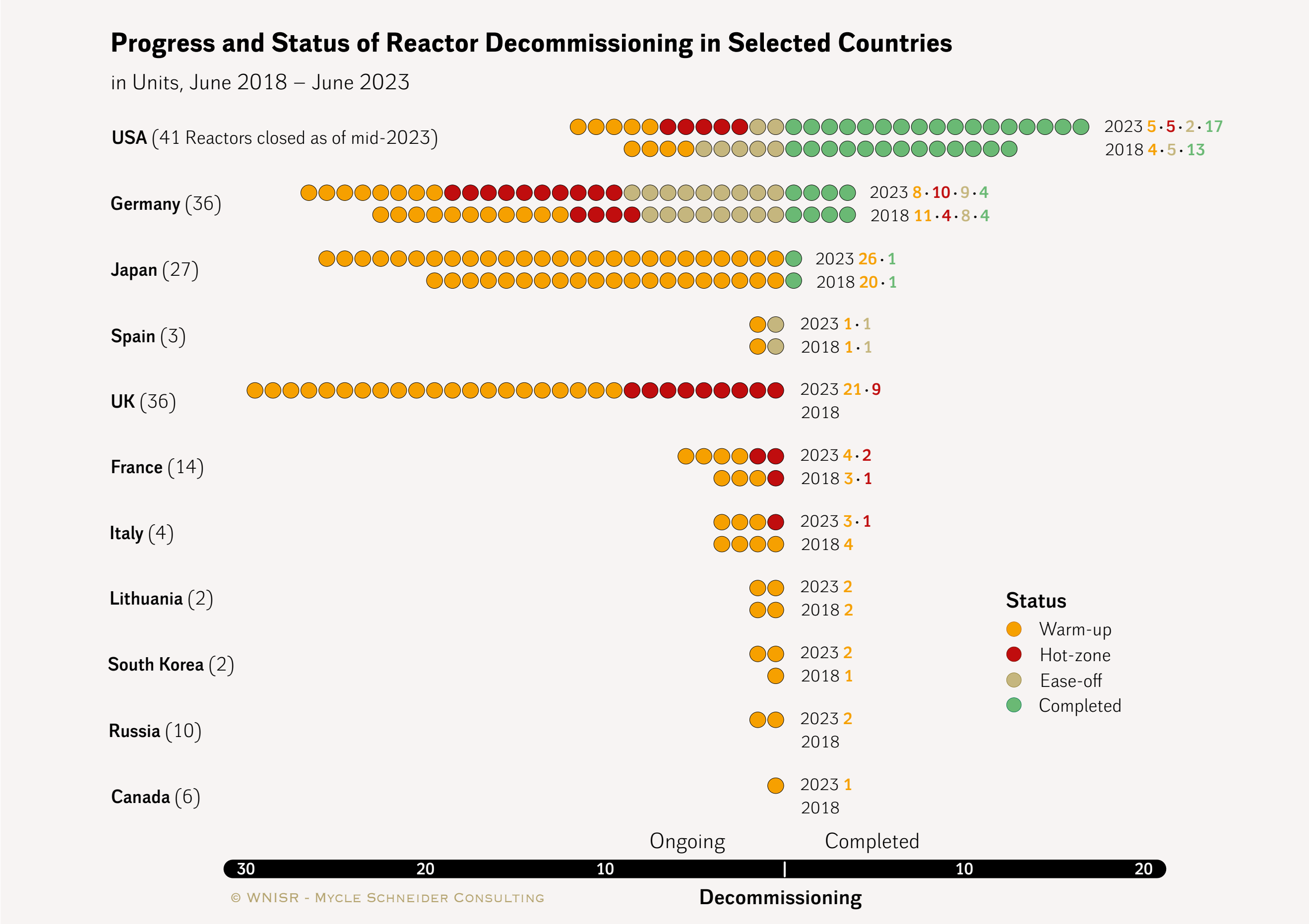
1083 - Power Technology, "Chernobyl Nuclear Power Plant Decommissioning, Ukraine", March 2022, see https://www.power-technology.com/projects/chernobyl/, accessed 9 June 2022; and Chornobyl NPP, "ChNPP Decommissioning", Undated, see https://chnpp.gov.ua/en/activity/chnpp-decommissioning, accessed 25 July 2023.

1084 - *WNN*, "Funding to bolster fire safety at Chernobyl", *World Nuclear News*, 15 November 2022, s ee https://www.world-nuclear-news.org/Articles/Funding-to-bolster-fire-safety-at-Chernobyl; and Christopher Booth, "The EBRD calls for Chernobyl support after Russia's occupation", European Bank for Reconstruction and Development, 18 May 2022, see https://www.ebrd.com/news/video/the-ebrd-calls-for-chernobyl-support-after-russias-occupation.html, accessed 24 July 2023.

1085 - EBRD, "Chernobyl's New Safe Confinement", European Bank for Reconstruction and Development, Undated, see https://www.ebrd.com/what-we-do/sectors/nuclear-safety/chernobyl-new-safe-confinement.html, accessed 9 June 2022.

more short-term dismantling approach. Germany is also making progress, having ended the commercial operation of nuclear power plants in April 2023.

Figure 55 · Progress and Status of Reactor Decommissioning in Selected Countries



Sources: Various, compiled by WNISR, 2023

Notes: After a decommissioning strategy change, the U.K. has begun to move reactors from LTE to various stages of decommissioning.

COUNTRY CASE STUDIES

Canada

In Canada, no commercial reactor has been decommissioned so far. In mid-2023, six reactors (2.1 GW), including five CANDU (CANadian Deuterium Uranium) reactors and one Heavy-Water Moderated Boiling Light-Water Reactor (HWBLWR), were closed. Despite some closures having occurred decades ago, progress in Canada is slow. The 200-megawatt Douglas Point prototype CANDU reactor was closed in 1984 after 17 years of operation and remained in LTE until 2021.[1086] Currently, dismantling at auxiliary, non-nuclear buildings is ongoing, placing the reactor in the warm-up stage. The plan is to release the site from regulatory oversight in

1086 - CNL, "Douglas Point Prototype Reactor", Canadian Nuclear Laboratories, Undated, see https://www.cnl.ca/environmental-stewardship/decommissioning-the-douglas-point-prototype-reactor/, accessed 1 November 2023.

2070.[1087] Dismantling at Gentilliy-2 for example, is due to begin in 2057.[1088] Prior to this, the reactor will be kept in LTE, and spent fuel is scheduled to be transported to a permanent site from 2048 to 2054. The site is planned to be fully restored by 2064, while an environmental follow-up will conclude by 2074[1089] (For more details on the Canadian decommissioning process, see WNISR2018.)

France

The closed reactor fleet in France is diverse in comparison to the current largely standardized operational PWR fleet. In total, 14 reactors (8 GCR, 3 PWR, 1 HWGCR, 2 FBR) have been closed, corresponding to approximately 5.5 GW. Apart from the reactors at the Marcoule site, for whose decommissioning the French Alternative Energies and Atomic Energy Commission (CEA) is responsible as owner (G-2, G-3) or co-owner (Phénix, 20 percent share belongs to EDF), all reactors are decommissioned by state-owned utility Électricité de France (EDF).[1090] Work is ongoing at several sites:

- Four reactors are in the warm-up stage: EL-4 (Brennilis), Fessenheim-1 & -2, and Phénix.
- Two reactors are in the hot-zone stage: Chooz-A, and Superphénix.

All GCRs (Bugey-1, Chinon A-1, A-2, A-3, and Saint-Laurent-des-Eaux A-1 & A-2) remain in LTE (as well as the G-2 and G-3 reactors at Marcoule).

Despite France's theoretical official strategy of "as-fast-as-possible decommissioning", the process is advancing slowly, but, according to French Nuclear Safety Authority ASN (Autorité de Sûreté Nucléaire) mostly satisfactory.[1091]

In the years to come, EDF will also have to manage decommissioning activities of its large currently operational PWR fleet. When exactly these units will enter their decommissioning phase depends on upcoming decisions concerning lifetime extensions. EDF hopes to use the Fessenheim reactors as test sites to learn best practices that can then be applied to other PWRs and reduce costs and necessary efforts for decommissioning.[1092]

For its six UNGG-type (Uranium Naturel Graphite Gaz) GCR reactors Chinon A-1, A-2, A-3, Saint-Laurent-des-Eaux A-1 & A-2 and Bugey-1, EDF in 2001 initially adopted a deferred dismantling strategy by flooding the reactor vessel with water and then planning to perform

1087 - Ibidem; and Jill Charlebois, "Douglas Point Decommissioning Work Continues", *Bayshore Broadcasting*, 5 August 2022, see https://www.bayshorebroadcasting.ca/2022/08/05/final-douglas-point-decommissioning-phase-begins/, accessed 1 November 2023.

1088 - Hydro-Québec, "Almost 10 years ago, Hydro-Québec permanently shut down the Gentilly-2 nuclear reactor", Press Release, 19 December 2022, see c, accessed 23 June 2023.

1089 - Hydro-Québec, "Construction Work and Projects—Decommissioning of the Gentilly-2 facilities", Undated, see https://www.hydroquebec.com/projects/decommissioning-gentilly-2/, accessed 31 August 2023.

1090 - ASN, "Les Appréciations de l'ASN", Autorité de sûreté nucléaire/French Nuclear Safety Authority, May 2023 (in French), see https://www.french-nuclear-safety.fr/content/download/189732/file/Appr%C3%A9ciations%20de%20l%27ASN%20-%20Rapport%20annuel%20de%20l%27ASN%202022.pdf, accessed 22 June 2023.

1091 - Ibidem.

1092 - Christophe Martin, Aurélien Portelli and Franck Guarnieri, "Myths and representations in French nuclear history: The impact on decommissioning safety", presented at "22nd European Safety and Reliability Conference—ESREL 2013", 29 September-2 October 2013, see https://mines-paristech.hal.science/hal-00868830/document, accessed 25 July 2023; and "ASN, "ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020", August 2021, op. cit.

decommissioning procedures underwater.[1093] However, due to France's official "as-fast-as-possible" decommissioning strategy and substantial technical challenges of underwater dismantling, EDF decided in 2016 to change the strategy to in-air dismantling. Resulting changes in decommissioning plans prompted ASN to demand new decommissioning licensing applications for all six reactors in 2020,[1094] which were submitted by EDF in December 2022. The expected date for their grant has been moved from late 2025 to end of 2026. Thus, initial targets for dismantling no later than 2031 have been scrapped. EDF's current plans envision reactor vessel internals and graphite block removal at Chinon A-2 to begin in 2034 and last until 2055. By 2037, all other reactors are scheduled to be placed into a "safe storage configuration" (LTE) for decommissioning to commence by 2056. Compared to last year's estimations, total decommissioning costs for all six GCR plants have increased by €400 million to €7 billion (US$7.67 billion).[1095]

The PWR reactor at Chooz-A was closed in 1991 and has been undergoing decommissioning work since 2007. The reactor itself is being dismantled in an underwater procedure. The dismantlement of reactor internals was completed in February 2021, and cutting of the reactor vessel was planned for 2023 after the pool had been drained.[1096] Last year, EDF had expected to complete these tasks by 2024. But in the meantime, the target has been pushed back to December 2025.[1097] The latest documents state that final dismantling of the reactor will be completed over the course of 2026.[1098] Once this is completed, final dismantling of remaining equipment and demolition of buildings can begin. The original plan issued in 2007 expected Chooz-A to be fully delicensed by 2047, but under the new full continuous decommissioning scenario adopted in 2021, delicensing is expected in 2035. Due to the site's unique location in a cave, unexpected difficulties have led to multiple cost increases, the last two amounting to additional €114 million (US$124.5 million) in provisions (€77 million in 2021 and €37 million in 2022).[1099]

The two PWRs at Fessenheim were closed in 2020. EDF currently plans a six-year preparatory phase until the decommissioning license is obtained, which is expected in 2026. Currently, defueling of both reactors, as well as boron removal, and the chemical decontamination of the primary circuit of Unit 1 are underway and on schedule. The beginning of decontamination works at Unit 2 has been postponed to 2023, although EDF says that the plan is still on track. The total cost is currently estimated at €1 billion (US$1.09 billion) for both units.[1100]

1093 - ASN, "ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020", August 2021, op. cit.

1094 - ASN, "Rapport de l'ASN sur l'état de la sûreté nucléaire et de la radioprotection en France en 2022", Annual Report (in French), Autorité de sûreté nucléaire/French Nuclear Safety Authority, May 2023, see https://www.asn.fr/l-asn-informe/publications/rapports-de-l-asn/la-surete-nucleaire-et-la-radioprotection-en-france-en-2022, accessed 22 June 2023.

1095 - EDF, "Consolidated Financial Statements at 31 December 2022", Électricité de France, February 2023, see https://www.edf.fr/sites/groupe/files/2023-02/annual-results-2021-consolidated-financial-statements-2023-02-17.pdf, accessed 22 June 2023.

1096 - EDF, "Universal Registration Document 2021 - Including the Annual Financial Report", Électricité de France, March 2022, see https://www.edf.fr/sites/groupe/files/2022-03/edf-2021-universal-registration-document.pdf, accessed 29 March 2022.

1097 - EDF, "Consolidated Financial Statements at 31 December 2022", February 2023, op. cit., p. 89.

1098 - EDF, "Le réacteur nucléaire de Chooz A", Press Briefing (in French), Électricité de France, 2023, see https://www.edf.fr/sites/groupe/files/2023-01/Chooz%20A%20-%20Fiche%20presse%202023.pdf, accessed 31 August 2023.

1099 - EDF, Consolidated Financial Statements at 31 December 2022", op. cit.; and EDF, "Universal Registration Document 2021 - Including the Annual Financial Report", March 2022, see https://www.edf.fr/sites/groupe/files/2022-03/edf-2021-universal-registration-document.pdf, accessed 5 April 2022.

1100 - EDF, "Consolidated Financial Statements at 31 December 2022", February 2023, op. cit.

In 2011, the EL-4 reactor at Brennilis (Monts d'Arrée), that was closed in 1985, received a partial decommissioning license for parts outside the nuclear island. Since then, progress has been made, such as spent fuel removal and machine room dismantling. While ASN says that preparations by EDF for dismantling to continue were satisfactory,[1101] the utility is still awaiting ASN's approval to begin further work on the reactor itself, expected to be granted sometime in 2023.[1102] These operations are planned to be completed by 2040. Most recent estimates place total decommissioning costs for this single reactor at €960 million (US$1.05 billion).[1103] The project has been experiencing cost overruns since the beginning of preparatory works after closure. In 1999, provisions were increased from a maximum of €30 million ($\mathrm{US\$}_{1999}$30.2 million) until then to €200 million ($\mathrm{US\$}_{1999}$201.5 million). By 2002, costs were estimated at €$_{2002}$482 million ($\mathrm{US\$}_{2002}$456 million).[1104]

The FBR reactor Superphénix at Creys-Malville has been undergoing decommissioning since 2006. Currently, reactor vessel internals are being dismantled. This is expected to be completed by 2026, with the current target for the whole site to be released from regulatory oversight by 2034, four years sooner than last year's estimate. Compared to last year, decommissioning cost estimations have nonetheless risen by €100 million to €1.9 billion ($\mathrm{US\$}_{2023}$2.08 billion). This figure is assumed to be "four times as high" as for PWR dismantling.[1105] It is worth noting that compared to last year's plans, EDF added at least one year to most estimated dates, and has increased total cost estimates by several hundred million euros (see Case Sutdy on France in Decommissioning Status Report, WNISR2022).

Decommissioning of the FBR Phénix at Marcoule began shortly after its closure in 2009. After disruptions during the COVID-19-lockdown in 2020, work on fuel and equipment removal has since continued. Currently, the removal of sodium poses the greatest challenge, and is expected to be completed by 2037. Then, further dismantling can continue. Completion of fuel removal has been "postponed by several years" beyond the planned completion data of 2025.[1106]

The remaining GCR plants G-2 and G-3, also located at Marcoule, are currently in LTE after having been defueled and partly dismantled. Graphite removal was supposed to begin in 2020, but no indication on progress could be identified. [1107] The last documented target completion date for the steps of graphite removal and reactor dismantling was published in 2020 as "at

1101 - Karen Jego, "L'Autorité de sûreté nucléaire se dit « satisfaite » de la préparation du démantèlement complet de la centrale de Brennilis", *Le Télégrame*, 15 June 2023 (in French), see https://www.letelegramme.fr/finistere/brennilis-29690/lautorite-de-surete-nucleaire-se-dit-satisfaite-de-la-preparation-du-demantelement-complet-de-la-centrale-de-brennilis-6373491.php, accessed 22 June 2023.

1102 - *Ouest France*, "2023 rime avec démantèlement et consommation électrique à Brennilis", 20 January 2023 (in French), see https://www.ouest-france.fr/bretagne/brennilis-29690/2023-rime-avec-demantelement-et-consommation-electrique-a-brennilis-dc1af738-98c9-11ed-838e-db5cb73079c3, accessed 22 June 2023.

1103 - EDF, "Consolidated Financial Statements at 31 December 2022", February 2023, op. cit., p.89–90.

1104 - Mycle Schneider Consulting, "Comparison Among Different Decommissioning Funds Methodologies for nuclear Installations—Country Report France—Final Report", Wuppertal Institut für Klima, Umwelt, Energie GmbH, on behalf of the Directorate-General Energy and Transport, European Commission, 2007, see https://epub.wupperinst.org/frontdoor/deliver/index/docId/2613/file/2613_EUDecommFunds_FR.pdf, accessed 30 August 2023.

1105 - EDF, "Consolidated Financial Statements at 31 December 2022", February 2023, op. cit.

1106 - ASN, "Rapport de l'ASN sur l'état de la sûreté nucléaire et de la radioprotection en France en 2022", May 2023, op. cit.

1107 - CEA, "Dossier de Presse—Démantèlement", Commissariat à l'énergie atomique et aux énergies alternatives/French Alternative Energies and Atomic Energy Commission (in French), April 2015, see https://www.francetnp.gouv.fr/IMG/pdf/dossier_de_presse_demantelement_-_2015_v2.pdf, accessed 17 May 2022.

best" before 2040, while the responsible operator CEA "no longer envisages to complete decommissioning before 2090".[1108]

Germany

After a politically turbulent summer of 2022, the closure dates for reactors Emsland (operated by RWE), Isar-2 (operated by PreussenElektra), and Neckarwestheim-2 (operated EnBW), were postponed by three and a half months from end-2022 (see Germany Focus). These reactor closures on 15 April 2023 marked the end of commercial nuclear power plant operations in Germany. As of July 2023, Germany has 36 closed reactors, corresponding to 26.4 GW.

Of the larger commercial reactors, only the 640-MW Würgassen unit has de facto completed the technical decommissioning process. However, Würgassen cannot be released from regulatory control as buildings onsite are used for interim nuclear-waste storage. Several other commercial reactors have finalized the hot-zone stage and have moved on to the ease-off stage. Smaller prototype or demonstration reactors HDR Großwelzheim, Niederaichbach, and VAK Kahl have all been fully decommissioned and released from regulatory control. The prototype pebble-bed, thorium high-temperature reactor THTR-300 is the only German reactor still in LTE. Recently closed plants Grohnde, Brokdorf, Isar-2, and Emsland all submitted decommissioning license applications but are waiting for approval. Work has not yet begun on site.[1109] See WNISR2022 for further details on the German nuclear decommissioning procedure.

Currently, decommissioning work is being conducted at 27 reactors.

- Eight reactors are in the warm-up stage: Biblis-A & -B (both defueled), Gundremmingen-B & -C, Krümmel (defueled), Lingen (defueled), Neckarwestheim-2, and Philippsburg-2 (defueled).
- Ten reactors are in the hot-zone stage: AVR Jülich, Brunsbüttel, Grafenrheinfeld, Isar-1, KNK II, Mülheim-Kärlich, Neckarwestheim-1, Obrigheim, Philippsburg-1, and Unterweser.
- Nine reactors are in the ease-off stage: Greifswald 1–5, Gundremmingen-A, MZFR, Rheinsberg, and Stade.

Grafenrheinfeld, a 1200-MW PWR, was closed in June 2015 after having operated for 34 years. The reactor completed defueling in May 2020, and work is now ongoing to dismantle the reactor pressure vessel. This task is estimated to be completed by 2033, when conventional demolition can begin. The plant is scheduled for release from regulatory oversight by 2035.[1110]

The nuclear power plant Isar (also referred to as Ohu) consists of two reactors, Isar-1, an 878-MW BWR closed in 2011, and Isar-2, a 1,400 MW PWR, that ceased operation in April 2023. At Isar-1, decommissioning has been underway since 2017, and current tasks involve reactor

1108 - Cour des comptes, "L'arrêt et le démentèlement des installations nucléaires", February 2020 (in French), see https://www.ccomptes.fr/system/files/2020-03/20200304-rapport-arret-demantelement-installations-nucleaires-2_0.pdf, accessed 31 August 2023.

1109 - BASE, "Nuclear Facilities in Germany—Part II: Nuclear Facilities 'In Decommissioning'", Bundesamt für die Sicherheit der nuklearen Entsorgung/Federal Office for the Safety of Nuclear Waste Management, May 2023 (in German), see https://www.base.bund.de/SharedDocs/Downloads/BASE/EN/reports/kt/nuclear-facilities-decommissioning.pdf?__blob=publicationFile&v=26, accessed 22 June 2023.

1110 - Deutscher Bundestag, "Bericht nach § 7 des Transparenzgesetzes—Rückbau von Kernkraftwerken", Report 20/4558 (in German), German Bundestag, 22 November 2022, see https://dserver.bundestag.de/btd/20/045/2004558.pdf, accessed 22 June 2023.

pressure vessel dismantling. Isar-1 is to be fully decommissioned by 2038. Isar-2 applied for a decommissioning license in 2019, the authorization by Bavarian authorities is expected by end-2023. The operator plans to complete decommissioning of Isar-2 by 2039.[1111]

The reactor Krümmel was officially closed in 2011 but had not generated electricity since 2009. In 2015, the operator applied to local authorities of the state of Schleswig-Holstein to decommission the plant.[1112] State authorities expect the permit to be granted in the second half of 2023, while some local politicians say that the decision was "well overdue", as the process at Krümmel marks the longest of all German nuclear power plants.[1113] During the application process, the operator was allowed to defuel the plant. Despite these delays, the operator hopes to complete decommissioning of Krümmel by 2039.[1114] As a major step of the warm-up stage, defueling, has already been completed, WNISR considers Krümmel to be in this stage, although a permit has not yet been granted.

The 1200-MW PWR Mülheim-Kärlich only generated power for 18 months until errors in the licensing process became public and the plant was closed in September 1988. The plant has been free of spent fuel since 2002, and since 2004, dismantling of components has been underway. Towards the end of 2022, operator RWE began an underwater dismantling process of the reactor internals, a task that is planned to be completed by 2025. Some areas that have already been released from the nuclear license were sold to investors, and apparently, plans are being made to build a hotel, as the site lies directly on the banks of the Rhine River.[1115] After the release from regulatory oversight, RWE plans complete demolition of remaining non-contaminated structures in the early 2030s.[1116]

The Neckarwestheim site consists of two PWRs. Neckarwestheim-1 has been in decommissioning since 2017 and completed reactor pressure vessel dismantling in December 2021. Work in the hot-zone is ongoing.[1117] Neckarwestheim-2, although only having recently been closed, has already begun decommissioning. The decommissioning license had been granted a few days before the reactor closed in April 2023.[1118] Spent fuel will remain in wet

1111 - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes—Rückbau von Kernkraftwerken", Drucksache 20/4558, 2022, op. cit.

1112 - KKK, "Kernkraftwerk Krümmel—Antrag nach §7 Abs. 3 AtG auf Stilllegung und Abbau Kernkraftwerk Krümmel", Kernkraftwerk Krümmel GmbH & Co, 24 August 2015, see https://www.schleswig-holstein.de/DE/fachinhalte/R/reaktorsicherheit/Downloads/Stillegung_Antrag_nach_AtG_KKK.pdf?__blob=publicationFile&v=1, accessed 4 July 2022; and Deutscher Bundestag, "Bericht nach § 7 des Transparenzgesetzes—Rückbau von Kernkraftwerken", Drucksache 20/42, German Bundestag, 4 November 2021, see https://dserver.bundestag.de/btd/20/000/2000042.pdf, accessed 5 April 2022.

1113 - Dirk Palapies, "Atomkraftwerk Krümmel: Startet der Rückbau noch dieses Jahr?", *Lauenburgische Landeszeitung*, 11 January 2023 (in German), see https://www.abendblatt.de/region/kreis-lauenburg/geesthacht/article237340603/vattenfall-atomkraftwerk-kruemmel-geesthacht-wann-startet-endlich-der-rueckbau.html, accessed 22 June 2023.

1114 - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes—Rückbau von Kernkraftwerken", Drucksache 20/4558, 2022, op. cit.

1115 - *SWR*, "AKW Mülheim-Kärlich: Rückbau im radioaktiven Bereich", *Südwestrundfunk*, 15 May 2023 (in German), see https://www.swr.de/swraktuell/rheinland-pfalz/koblenz/akw-muelheim-kaerlich-rueckbau-110.html, accessed 22 June 2023.

1116 - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken", Report 20/4558, op. cit.

1117 - Ibidem.

1118 - BASE, "Nuclear Facilities in Germany—Part II: Nuclear Facilities 'In Decommissioning'", May 2023, op. cit.

storage for up to four years, and first dismantling is due to begin over the course of the second half of 2023.[1119]

At the Philippsburg site, two reactors are currently undergoing decommissioning. Philippsburg-1, a BWR that ceased operations in 2011, is currently in the hot-zone as reactor dismantling advances.[1120] Decommissioning has been ongoing at Philippsburg-2, a 1400-MW PWR, since 2020. The reactor was defueled in the first half of 2023. Preparations to move on to reactor internals dismantling have commenced.[1121]

The 640-MW PWR at Stade is being decommissioned since 2005. After having dismantled all reactor internals in 2011, less contaminated structures were decommissioned until 2022. Since then, conventional demolition of remaining buildings has begun, and is expected to be completed by the end of 2026.[1122]

Italy

Since 1988, Italian nuclear power plants have not produced any electricity, and the last two reactors were officially closed in 1990. Since then, decommissioning at all four facilities has been underway, conducted by Italian agency Sogin. All four sites are to be released as brownfield.

The smallest reactor Garigliano, a 150-MW BWR, is in the hot-zone stage as reactor dismantling continues, envisioned to be completed by 2025.[1123] A tender for removal of activated metal plates inside the reactor was launched in 2022,[1124] but there has been no indication whether a bidder has been selected. Another tender, valued at €36 million (~US$39.6 million) was launched in August 2023 with the aim of contracting underwater dismantling of the reactor vessel and its internals. For unknown reasons, the end date for this process was pushed back by two years to end 2027.[1125]

At Italy's largest reactor, the 860-MW BWR Caorso, Sogin is making progress, reporting in March 2023 that it had completed 48 percent of the planned activities since decommissioning began in 1999, a notable 10 percent progress made in 2022 alone. Work is being further carried

1119 - Jens Nising, "Rückbau des Atomkraftwerks Neckarwestheim gestartet", *Südwestrundfunk* (in German), 22 May 2023, see https://www.swr.de/swraktuell/baden-wuerttemberg/heilbronn/rueckbau-atomkraftwerk-neckarwestheim-2-hat-begonnen-100.html, accessed 22 June 2023.

1120 - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes—Rückbau von Kernkraftwerken", Report 20/4558, 2022, op. cit.

1121 - EnBW, "KKP 2 befindet sich seit 2020 im Rückbau", Energie Baden-Württemberg AG, 2023 (in German), see https://www.enbw.com/unternehmen/konzern/energieerzeugung/kernenergie/rueckbau/stilllegung-und-abbau-kkp-2.html, accessed 22 June 2023.

1122 - Preussen Elektra, "Konventioneller Abbruch des Kernkraftwerks Stade beginnt", Press Release (in German), 13 April 2023, see https://www.preussenelektra.de/de/newsroom/pressemitteilungen/pressemitteilungen-2023/kks-konventioneller-abriss-beginnt.html, accessed 25 July 2023.

1123 - Sogin, "Garigliano Nuclear Power Plant—Decommissioning Projects—Reactor dismantling", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/gariglianonuclearpowerplant/decommissioningprojects/reactor-dismantling.html, accessed 23 June 2023.

1124 - Sogin, "Garigliano, launched the call for tender for the dismantling of internals", 20 April 2022, see https://www.sogin.it/en/media/news/garigliano-launched-the-call-for-tender-for-the-dismantling-of-internals.html, accessed 24 June 2022.

1125 - *WNN*, "Tender issued for removal of Italian reactor vessel", *World Nuclear News*, 3 August 2023, see https://www.world-nuclear-news.org/Articles/Tender-issued-for-removal-of-Italian-reactor-vesse; and Sogin, "Avviate Le Gare Per Smantellare Il Reattore Della Centrale Del Garigliano E Per Realizzare L'Impianto Magnox A Latina", Press Release (in Italian), 1 August 2023, see https://www.sogin.it/SiteAssets/uploads/2023/notizie/com-stampa-Sogin-Avviate-le-gare-per-smantellare-reattore-centrale-del-garigliano-e-realizzare-impianto-magnox-a-latina.pdf, accessed 5 November 2023.

out to expand temporary waste storage facilities.[1126] Reactor internal dismantling is expected to begin in 2026 and be completed by 2030.[1127]

At the Enrico Fermi (Trino) plant, tenders for reactor internals dismantling are being prepared.[1128] There has been no update since WNISR2021, but Sogin has pushed the expected completion date for brownfield decommissioning back by one year to 2030. Work had begun in 1999.[1129]

Italy is currently in the process of finding a final waste repository, with radioactive waste currently being stored at ten interim storage facilities spread across the country. A map of potential locations for the final repository was released in 2022.[1130] Until this repository is available, the Latina GCR cannot be fully decommissioned. The reactor is of the Magnox design (of which several are under decommissioning in the U.K.) and thus contains several tons of highly contaminated graphite. Sogin plans to gradually reduce the height of the reactor building by 20 meters from 2025 to 2027, following the U.K.'s approach at Windscale.[1131] (See WNISR2019 and WNISR2020 for detailed information on decommissioning in Italy.)

Japan

As of mid-2023, 27 reactors or 17.1 GW were permanently disconnected from the grid in Japan. The country, as one of the early adopters of nuclear power, has not completed decommissioning of a single commercial reactor, and the only accomplished decommissioning project is the small 12-MW research reactor Japan Power Demonstration Reactor (JPDR). Physical decommissioning work had lasted from 1986 to 1996, and the site was used as test site for demonstration techniques.[1132] In October 2002, the JPDR was released from regulatory oversight as a greenfield site.[1133]

1126 - Emilia-Romagna Notizie, "Ex centrale nucleare di Caorso, lo smantellamento verso il 50%. In arrivo un accordo Sogin-Regione: circa 10 milioni di euro dalle compensazioni ambientali per la riqualificazione e la valorizzazione del tratto piacentino del Po", Press Release (in Italian), 31 March 2023, see https://notizie.regione.emilia-romagna.it/comunicati/2023/marzo/ambiente-ex-centrale-nucleare-di-caorso-lo-smantellamento-verso-il-50-in-arrivo-un-accordo-sogin-regione-circa-10-milioni-di-euro-dalle-compensazioni-ambientali-per-la-riqualificazione-e-la-valorizzazione-del-tratto-piacentino-del-po, accessed 23 June 2023.

1127 - Sogin, "Smantellamento edificio reattore", Undated (in Italian), see https://www.sogin.it/it/chiusuradelciclonucleare/sitinucleariitaliani/centraledicaorso/progettididecommissioning/Pagine/Smantellamento-edificio-reattore.aspx#, accessed 23 June 2023.

1128 - Sogin, "Trino Nuclear Power Plant/Decommissioning Projects—Reactor Dismantling", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/trinonuclearpowerplant/decommissioningprojects/reactor-dismantling.html, accessed 23 June 2023.

1129 - Sogin, "Nuclear Sites—Trino Nuclear Power Plant", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/trinonuclearpowerplant/Pagine/default.aspx, accessed 11 September 2023.

1130 - Maria Rosaria Di Nucci and Andrea Prontera, "Nuclear Waste Governance in Italy: Between Participation Rhetoric and Regionalism", in Maarten Arentsen and Rinie Van Est, "The Future of Radioactive Waste Governance", *Springer Fachmedien Wiesbaden*, 2023, pp.51–83, see https://link.springer.com/10.1007/978-3-658-40496-3_3, accessed 23 June 2023.

1131 - Sogin, "Dismantling of the reactor building", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/decommissioningprojects/dismantling-of-the-reactor-building.html, accessed 25 July 2023.

1132 - JAEA, "JPDR(Japan Power Demonstration Reactor)", Japan Atomic Energy Agency, Undated, see https://www.jaea.go.jp/english/04/ntokai/decommissioning/01/decommissioning_01_01_01.html; and JAEA, "Decommissioning Facility", Undated, see https://www.jaea.go.jp/english/04/ntokai/decommissioning/01/decommissioning_02.html; both accessed 5 November 2023.

1133 - Satoshi Yanagihara, "Outcome of the Japan Power Demonstration Reactor Decommissioning Project", Research Institute of Nuclear Engineering, University of Fukui, presented at "2019 Sino-Japanese Workshop on NPP Decommissioning Technology", Atomic Energy Council 3F, 29–30 October 2019.

The decommissioning of the Magnox reactor Tokai-1 started in 2001. The turbines have been dismantled and reactor dismantling is to begin in 2024 with the goal to complete decommissioning by 2030.[1134]

The decommissioning of Fugen ATR started in 2008. Radiological decommissioning is planned to be completed by 2038, while finalization of building demolition is expected by 2040.[1135] Work on Hamaoka-1 and -2 began in 2009 and is to last until 2036.[1136]

Mihama-1 and -2, Shimane-1, and Tsuruga-1 received their decommissioning licenses in 2017.[1137] Apart from Tsuruga, which is to be decommissioned by 2039, completion dates are placed at 2045.[1138]

Clean-up at the Fukushima Daiichi plant is slowly advancing as fuel is being removed from the six reactors. The main challenges lie within the determination of the composition of debris in the damaged containment chambers of Units 1–3. Removal of this debris is to begin in September 2023 at Unit 2, two years later than originally planned. Unit 1 will be defueled from 2027 onwards, after buildings that had been damaged by the hydrogen explosions are planned to have been dismantled.[1139] Units 3 and 4 were defueled in December 2014 and February 2021, respectively.[1140] Units 5 and 6 are to be defueled by 2031.[1141] Then, actual dismantling is to begin, and the Japanese government hopes to complete the task for the whole site by 2051. This is contested as some say that "removing all of the melted fuel debris by [2031] is impossible" and thus propose a "Chernobyl-style entombment."[1142] (See Fukushima Status Report for details).

Fukushima Daini, a four-unit BWR located approximately 11 kilometers south of Fukushima Daichi was shut down after the 2011 earthquake and officially permanently closed in 2019 when owner TEPCO announced its decision to decommission the plant.[1143] Work is to go on until 2064.[1144]

In 2019, U.K.-based company Cavendish Nuclear won a contract to support decommissioning of the Fast Breeder Reactor (FBR) Monju; it is expected that work will last around 30 years and

1134 - JAPC, "敦賀発電所1号機の廃止措置—廃止措置工事のスケジュール" ["Decommissioning of NPP Tsuruga 1"], The Japan Atomic Power Company, 19 April 2017 (in Japanese), see http://www.japc.co.jp/tsuruga/haishi/dai1_schedule.html, accessed 8 June 2022.

1135 - FUGEN Decommissioning Engineering Center, "Basic Schedule of Decommissioning", Japan Atomic Energy Agency, Undated, see https://www.jaea.go.jp/04/fugen/en/haishi/plan/processl/, accessed 11 September 2023.

1136 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2023/07/jp-npps-operation20230710_en.pdf, accessed 4 November 2023.

1137 - *WNN*, "Decommissioning plans approved for five Japanese units", *World Nuclear News*, 19 April 2017, see https://www.world-nuclear-news.org/Articles/Decommissioning-plans-approved-for-five-Japanese-u, accessed 8 June 2022.

1138 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

1139 - Mari Yamaguchi, "Fukushima plant head: Too early to predict decommissioning", *The Associated Press*, 3 March 2023, see https://apnews.com/article/japan-fukushima-nuclear-plant-decommissioning-a2c9538ce60e8a09c69d446cc5206f84, accessed 21 June 2023.

1140 - Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, "Outline of Decommissioning, Contaminated Water and Treated Water Management", Ministry of Economy, Trade and Industry, Government of Japan, April 2023, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/mp202304.pdf, accessed 21 June 2023.

1141 - TEPCO, "Roadmap on the Way to Decommissioning", Tokyo Electric Power Company Holdings, 2022, see https://www.tepco.co.jp/en/hd/decommission/project/roadmap/index-e.html, accessed 8 June 2022.

1142 - Mari Yamaguchi, "Fukushima plant head: Too early to predict decommissioning", *The Associated Press*, 3 March 2023, op. cit.

1143 - *WNN*, "Tepco declares Fukushima Daini for decommissioning", *World Nuclear News*, 31 July 2019, see https://www.world-nuclear-news.org/Articles/Tepco-declares-Fukushima-Daini-for-decommissioning, accessed 12 September 2023.

1144 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

cost more than ¥375 billion (US$$_{2019}$3.4 billion).[1145] Fuel was removed from sodium-filled tanks to wet storage in October 2022, completing the first of four stages of decommissioning. The next steps are to extract the liquid sodium coolant from the reactor and dismantle internal equipment. The reactor building is to be demolished by 2047.[1146]

In 2020, Kyushu Electric Power filed the decommissioning license application for the Genkai-2 reactor with NRA. Defueling of Unit 2 is expected to occur from 2026 to 2040. Kyushu Electric Power also requested approval to change its ongoing decommissioning plan for Genkai-1, which would push back the completion target-date from 2043 to 2054. According to the operator, the reason for this was that the slowdown at Unit 1 would allow decommissioning at Unit 2 to catch up, so that works at both units could eventually be carried out simultaneously.[1147] Recent information shows that the target date for completing decommissioning was fixed to 2054 for both reactors.[1148] For the decommissioning of Genkai-1 and -2, Kyushu operates a special account related to decommissioning, that, in 2021, held approx. US$379 million[1149], and had been reduced to US$323 million by 2022.[1150]

At Ikata-1, decommissioning work began in January 2021, when the unit entered the first phase of decommissioning (fuel removal and dismantling of secondary system equipment), which is expected to go on until "around FY2026".[1151] In October 2020, the NRA approved the decommissioning license for Ikata-2. Defueling of the reactor is scheduled to be carried out during the preparatory stage lasting ten years.[1152] Current estimations put completion dates at 2056 for Ikata-1 and 2059 for Ikata-2.[1153]

In 2019, Units 1 and 2 of the Ohi nuclear plant received their decommissioning license approval by Japanese authorities. Both PWRs had ceased operations in 2011, and after estimating retrofitting costs at ¥830 billion (US$$_{2023}$5.8 billion) to comply with new safety standards, operator Kansai in 2017 announced that both reactors would be decommissioned.[1154] Decommissioning is planned to be completed by 2048 at both units.[1155]

1145 - *NEI Magazine*, "Cavendish wins contract to help with Monju decommissioning", 2 September 2019, see https://www.neimagazine.com/news/newscavendish-wins-contract-to-help-with-monju-decommissioning-7394600, accessed 16 August 2020.

1146 - *WNN*, "Defuelling completed at Japan's Monju reactor", *World Nuclear News*, 21 October 2022, see https://world-nuclear-news.org/Articles/Defuelling-completed-at-Japan-s-Monju-reactor, accessed 21 June 2023.

1147 - Asian Power, "Kyushu Electric Power to decommission Genkai-2 Nuclear Power Plant", 2020, see https://asian-power.com/power-utility/news/kyushu-electric-power-decommission-genkai-2-nuclear-power-plant, accessed 27 June 2022.

1148 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

1149 - Kyuden Group, "Integrated Report 2021", Kyushue Electric Power, September 2021, see https://www.kyuden.co.jp/library/pdf/en/ir/integratedreport/2021/en_integratedreport_2021.pdf, accessed 8 June 2022.

1150 - Kyuden Group, "Integrated Report 2022", Kyushue Electric Power, September 2022, see https://www.kyuden.co.jp/library/pdf/en/ir/integratedreport/2022/en_integratedreport_2022.pdf, accessed 21 June 2023.

1151 - Shikoku Electric Power Group, "Integrated Report 2021", December 2021, see https://www.yonden.co.jp/english/assets/pdf/ir/tools/ann_r/annual_e_2021.pdf, accessed 8 June 2022.

1152 - *WNN*, "Regulator approves Ikata 2 decommissioning plan", *World Nuclear News*, 7 October 2020, see https://www.world-nuclear-news.org/Articles/Regulator-approves-Ikata-2-decommissioning-plan, accessed 21 June 2023.

1153 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

1154 - *WNN*, "Regulator approves decommissioning plan for Ohi 1 and 2", *World Nuclear News*, 11 December 2019, see https://www.world-nuclear-news.org/Articles/Regulator-approves-decommissioning-plan-for-Ohi-1, accessed 12 September 2023.

1155 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, op. cit.

While Units 2 and 3 of the Onagawa plant remain in long-term outage since 2011, Unit 1 was officially permanently closed in 2018 and is to be decommissioned by 2053.[1156] The decision to dismantle Onagawa-1 had been made in 2018 after it was deemed that "required safety upgrades would be too expensive and time-consuming". In 2019, decommissioning costs were estimated at ¥41.9 billion (US$$_{2019}$392 million).[1157]

Lithuania

In Lithuania, two reactors with 1185 MW each were closed in 2004 and 2009, respectively, as a pre-requisite for Lithuania to join the European Union. Both reactor cores are defueled and in May 2021, the last spent fuel assemblies were removed from the pool of Unit 1 and transported to an interim dry storage facility. The complete removal of the spent fuel from Unit 2 was achieved in April 2022.[1158] In early 2023, operator Ignalinos atominė elektrinė (IAE) signed two contracts, valued at US$5.8 million each, with a consortium of Westinghouse Electric Spain, Jacobs Slovakia, and the Lithuanian Energy Institute, and with another consortium, consisting of EDF and Graphitec. Both consortia are tasked with designing specialized technology to dismantle the RBMK reactors. Physical dismantling, with the aim of releasing a "brownfield" site in 2038, is planned to begin in 2028.[1159] (See WNISR2019 for details on decommissioning in Lithuania.)

Russia

As of mid-2023, Russia accounts for ten closed reactors with a combined capacity of 4 GW consisting of two different reactor types: seven first-generation Light-Water Gas-cooled Reactors (LWGR)—among them three RBMK Chernobyl-type reactors—and three Soviet-style PWRs.

In Russia, there was only little tangible progress in reactor decommissioning in recent years, apart from Leningrad-1 that was defueled in 2021[1160], and defueling at Leningrad-2 which was completed in August 2023. This marks the transfer of all 3,361 fuel assemblies from both reactors into "special storage pools".[1161]

1156 - Ibidem.

1157 - *WNN*, "Tohoku submits decommissioning plan for Onagawa 1", *World Nuclear News*, 2 August 2019, see https://www.world-nuclear-news.org/Articles/Tohoku-submits-decommissioning-plan-for-Onagawa-1, accessed 12 September 2023.

1158 - State Enterprise Ignalina Nuclear Power Plant, "The last cask of spent fuel was transported for temporary storage", Press Release, 22 April 2022, see https://www.iae.lt/en/news/press-releases/the-last-cask-of-spent-fuel-was-transported-for-temporary-storage/836; and *WNN*, "Defuelling of Ignalina units completed", 22 April 2022, see https://www.world-nuclear-news.org/Articles/Defuelling-of-Ignalina-units-completed; both accessed 5 November 2023.

1159 - State Enterprise Ignalina Nuclear Power Plant, "Ignalina NPP has signed two contracts", 12 January 2023, see https://www.iae.lt/en/news/press-releases/ignalina-npp-has-signed-two-contracts/929; and *WNN*, "Contracts for Ignalina dismantling technology", 4 January 2023, see https://www.world-nuclear-news.org/Articles/Contracts-for-Ignalina-dismantling-technology; both accessed 5 November 2023.

1160 - *WNN*, "Defuelling completed at Leningrad 1", *World Nuclear News*, 11 August 2021, see https://www.world-nuclear-news.org/Articles/Defuelling-completed-at-Leningrad-1, accessed 21 June 2023.

1161 - *WNN*, "Second Leningrad unit defuelled", *World Nuclear News*, 23 August 2023, see https://www.world-nuclear-news.org/Articles/Second-Leningrad-unit-defuelled, accessed 1 November 2023.

At Kursk-1, closed in December 2021, decommissioning is still to commence.[1162] Considering the long-anticipated decommissioning duration of 50 years and unclear decommissioning strategies, WNISR considers all other Russian reactors as in LTE as long as there is no documented evidence of decommissioning progress. (See WNISR2019 for details on decommissioning in Russia.)

Spain

Spain defines its national policy for reactor decommissioning in the official, periodically updated, "General Radioactive Waste Plan". The Spanish administration describes decommissioning and waste management as an essential public service and assigns these tasks by law to state-owned radioactive waste-management company Enresa (Empresa Nacional de Residuos Radiactivos S.A.).[1163] While the LTE strategy is being applied to the GCR Vandellos-1 (until 2028),[1164] all LWRs are planned to be directly dismantled to a greenfield status.

In June 2022, demolition of the turbine building at the José Cabrera (Zorita) reactor, that was closed in 2006, was completed.[1165] This marked the demolition of the last large building on-site, allowing for the release of the site in the coming years. Enresa is still working on final restoration and hopes to terminate the nuclear license by end-2024.[1166]

The 446-MW BWR Santa Maria de Garoña (Garoña-1) suspended operations in 2013 and was officially closed in 2017. Since then, work has been ongoing to prepare for the license transfer to Enresa. Once this is completed, the actual decommissioning procedure can begin.[1167] The license transfer was concluded in July 2023, meaning that a first decommissioning phase, consisting of fuel removal from the reactor core and turbine hall dismantling, can begin. For the second phase, consisting mainly of hot-zone work, a separate authorization is required.[1168]

1162 - *NEI Magazine*, "Russia permanently closes down Kursk 1", *Nuclear Engineering International*, 21 December 2021, see https://www.neimagazine.com/news/newsrussia-permanently-closes-down-kursk-1-9337101, accessed 8 June 2022.

1163 - By Article 38 bis of Law 25/1964 of the Nuclear Energy Act.

1164 - Enresa, "Dismantling of the Vandellós I Nuclear Power Plant", Empresa Nacional de Residuos Radiactivos S.A./Spanish Radioactive Waste Management Agency, Undated, see https://www.enresa.es/eng/index/activities-and-projects/dismantling-and-environmental-restoration/dismantling-of-vandellos-i-nuclear-power-plant, accessed 25 July 2023.

1165 - *WNN*, "Decommissioning milestone at Spain's Zorita plant", *World Nuclear News*, 27 June 2022, see https://www.world-nuclear-news.org/Articles/Decommissioning-milestone-at-Spain-s-Zorita-plant, accessed 9 July 2022.

1166 - Santiago Barra, "Desmantelada la primera central nuclear española, medio siglo después", *Guadalajara Diario* (in Spanish), 28 March 2023, see https://www.guadalajaradiario.es/provincia/55704-desmantelada-la-primera-nuclear-espanola-espanola-medio-siglo-despues.html, accessed 22 June 2023.

1167 - *Europa Press*, "El CSN realizó 14 inspecciones de seguridad en 2022 a la central nuclear de Garoña, a la espera de desmantelamiento", 14 April 2023 (in Spanish), see https://www.europapress.es/sociedad/noticia-csn-realizo-14-inspecciones-seguridad-2022-central-nuclear-garona-espera-desmantelamiento-20230414113048.html, accessed 22 June 2023.

1168 - Enresa, "Enresa asume la titularidad de la central nuclear de Garoña para acometer la primera fase de su desmantelamiento", Press Release (in Spanish), Empresa Nacional de Residuos Radiactivos S.A./Spanish Radioactive Waste Management Agency, 19 July 2023, see https://www.enresa.es/eng/index/about-enresa/publications-and-video-library/publications/category/8-notas-de-prensa?download=164:enresa-asume-la-titularidad-de-la-central-nuclear-de-garona-para-acometer-la-primera-fase-de-su-desmantel-amiento; and David Dalton, "Enresa Takes Ownership Of Garona As €475 Million Decommissioning Begins", *NucNet*, 21 July 2023, see https://www.nucnet.org/news/enresa-takes-ownership-of-garona-as-eur475-million-decommissioning-begins-7-5-2023; both accessed 5 November 2023.

Total dismantling costs are estimated at €475 million (US$520 million) and should be completed by 2033.[1169] (See WNISR2019 for details on the Spanish decommissioning process.)

South Korea

South Korea is running a large nuclear program, including 24 operating reactors, one reactor in LTO, and three units under construction. As of mid-2023, two commercial reactors had been closed. The first reactor, South Korea's oldest unit Kori-1, a 576-MW PWR was closed in 2017. Since the 2021 submission of the decommissioning application by operator Korea Hydro & Nuclear Power (KHNP) who had hoped to begin decommissioning in 2022, the application has been under review. As of July 2023, the approval had not yet been granted.[1170] In 2017, plans had envisioned defueling by end-2025 and the completion of plant dismantling by 2032.[1171]

Wolsong-1, a 661-MW Pressurized Heavy-Water Reactor (PHWR), ceased generating power in May 2017 but was officially only closed in December 2019.[1172] In November 2022, KHNP signed a Memorandum of Understanding with Canadian Candu Energy to join forces in decommissioning Wolsong-1 under a direct dismantling strategy, potentially making Wolsong-1 the first heavy-water reactor world-wide to undergo short-term decommissioning.[1173] No information is available as to the work schedule.

United Kingdom

In August 2022, the closure of both reactors at Hinkley Point B marked the next step of the process of gas-cooled reactor closures in the U.K. With these closures, eight AGRs remain operational: Hartlepool A-1 & -2, Heysham A-1 & A-2 and Heysham B-1 & B-2, as well as Torness-1 & -2. These are all scheduled to be closed by 2028.[1174]

As of mid-2023, the U.K. had a total of 36 closed reactors (corresponding to 7.75 GW) awaiting or in various stages of decommissioning. This fleet consists of 26 GCR Magnox reactors, two FBRs, seven AGRs, including the Windscale reactor at Sellafield, and one heavy-water reactor at Winfrith. The Nuclear Decommissioning Authority (NDA), the responsible state agency, has

1169 - Enresa, "Activities and Projects—Dismantling of the Santa María de Garoña Nuclear Power Plant", Empresa Nacional de Residuos Radiactivos S.A./Spanish Radioactive Waste Management Agency, 2023, see https://www.enresa.es/eng/index/activities-and-projects/dismantling-and-environmental-restoration/dismantling-of-the-santa-maria-de-garona-nuclear-power-plant; and Ignacio Fariza, "El Gobierno autoriza el desmantelamiento de la central nuclear de Garoña, inactiva desde 2012", *El País*, 17 July 2023 (in Spanish), see https://elpais.com/economia/2023-07-17/el-gobierno-autoriza-el-desmantelamiento-de-la-central-nuclear-de-garona-inactiva-desde-2012.html; both accessed 5 November 2023.

1170 - Shin Ha-nee, "Korean nuclear power plant prepares for safer, longer future", *Korea JoongAng Daily*, 17 July 2023, see https://koreajoongangdaily.joins.com/2023/07/17/business/industry/Korea-KHNP-nuclear/20230717161110091.html, accessed 12 September 2023.

1171 - Jane Chung, "South Korea to complete dismantling of oldest nuclear reactor by 2032", *Reuters*, 19 June 2017, see https://www.reuters.com/article/us-southkorea-nuclear-idUSKBN19A02R, accessed 8 June 2022.

1172 - KHNP, "Nuclear Power Operation – Plant Status", Korea Hydro & Nuclear Power, 31 December 2018, see http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101, accessed 27 March 2019; and KHNP, "Overview", Undated, see https://www.khnp.co.kr/eng/contents.do?key=414, accessed 5 November 2023.

1173 - Cho Jeehyun, "Korea Hydro & Nuclear Power teams up with Candu Energy to retire Wolsong 1", *Pulse* by *Maeil Business News Korea*, as published by *Invest Korea*, 23 November 2022, see https://www.investkorea.org/ik-en/bbs/i-465/detail.do?ntt_sn=491939&clickArea=enmain00019, accessed 21 June 2023.

1174 - *WNN*, "Hinkley Point B enters retirement", *World Nuclear News*, 1 August 2022, see https://www.world-nuclear-news.org/Articles/Hinkley-Point-B-enters-retirement, accessed 8 June 2023.

recently switched the decommissioning strategy from deferred to direct dismantling, moving several reactors into an active decommissioning status. Nonetheless, the NDA expects nuclear decommissioning to last well into the 22nd century.[1175]

Currently, 30 reactors are undergoing decommissioning:

- Twenty-one reactors are in the warm-up stage: Berkeley-1 & -2 (defueled), Chapelcross 1–4 (all defueled), Dounreay DFR, Dounreay PFR, Dungeness A-1 & A-2 (both defueled), Dungeness B-1 & B-2, Hinkley Point B-1 & B-2, Hunterston B-1 & B-2, Trawsfynydd-1 & -2 (both defueled), Windscale (defueled), and Wylfa-1 & -2 (both defueled),
- Nine reactors are in the hot-zone-stage: Hinkley Point A-1 & -2, Hunterston A-1 & A-2, Oldbury A-1 & A-2, Sizewell A-1 & A-2 and Winfrith.

Six reactors are currently in LTE.

For several years, the U.K.'s decommissioning industry had been organized in a so-called "Parent Body Organization" model, that attempted to bring private industry expertise to the challenge of nuclear decommissioning for efficiency gains. After it became apparent that this goal would not be achieved, the approach was retracted for the various site-license companies (SLC), that acted as operators of the various closed reactors, from 2016 onwards, and thus since 2021, ownership and decommissioning responsibility has fully returned to the NDA. Decommissioning is now conducted by the NDA via the individual SLCs, mainly Sellafield Ltd and Magnox Ltd.[1176]

Sellafield Ltd was the first SLC to be returned to full NDA ownership in 2016.[1177] This SLC is responsible for the cleanup at the Sellafield site, the oldest, largest, and most complex nuclear site in the U.K. The site houses legacy spent fuel pools and storage ponds, reprocessing plants, as well as nuclear reactors Calder Hall 1–4 (in LTE) and Windscale.[1178] Magnox fuel reprocessing ended only in July 2022, meaning that now, the removal of spent fuel and radioactive waste, stored in ponds and silos that have started to decay, is ongoing. In parallel, interim storage facilities are being built that will hold waste from Sellafield and spent fuel from all Magnox reactors and AGRs.[1179]

Magnox Ltd became an NDA subsidiary in 2019 and is responsible for decommissioning at Berkeley, Bradwell, Chapelcross, Dungeness A, Harwell, Hinkley Point A, Hunterston A, Oldbury A, Sizewell A, Trawsfynydd, Winfrith, and Wylfa, and since April 2023, for both

1175 - NDA, "Business Plan—Financial year beginning April 2023 to financial year ending March 2026", SG/2023/34, Nuclear Decommissioning Authority, April 2023, p.26, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1151390/Business_Plan_2023-2026_-_final_for_web.pdf, accessed 23 June 2023.

1176 - Alexander Wimmers, Rebekka Bärenbold et al., "Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production", Data Documentation 104, DIW Berlin, Department of Energy, Transportation, Environment of German Institute for Economic Research, Workgroup for Infrastructure Policy at TU-Berlin, Faculty of Business and Economics at University of Basel, January 2023, see https://www.diw.de/documents/publikationen/73/diw_01.c.864222.de/diw_datadoc_2023-104.pdf, accessed 26 January 2023.

1177 - Sellafield Ltd, "Corporate Plan 2016/17-2036", April 2017, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/627566/SEL11098_corporate-plan_web.pdf, accessed 25 April 2022.

1178 - NDA, "Business Plan—Financial year beginning April 2023 to financial year ending March 2026", April 2023, op. cit.

1179 - Samantha Subramanian, "Dismantling Sellafield: the epic task of shutting down a nuclear site", *The Guardian*, 15 December 2022, see https://www.theguardian.com/environment/2022/dec/15/dismantling-sellafield-epic-task-shutting-down-decomissioned-nuclear-site, accessed 17 December 2022.

FBRs at Dounreay.[1180] After changing its initial blanket strategy to a site-specific approach, the NDA is currently assessing the best approach for each site, and has selected several "lead and learn" sites.[1181] Consequently, sites are in various stages, but decommissioning dates have been pulled forward by several decades. Winfrith is planned to be the first site to be released from its nuclear license in 2036, while the estimates for most other sites range from the 2050s to 2080s.[1182] The latest development was reported at the Berkeley site, when it was announced in May 2023 that the demolition of the four "blower house structures" in which radioactive gas had been circulated during operations would be brought forward by 50 years. The demolition is expected to take eight years. In parallel, underground vaults containing several hundred of (metric) tons of radioactive fuel debris and sludge are to be emptied, and repacked waste will be transferred to an on-site interim storage facility.[1183]

EDF Energy, subsidiary of French state-owned utility EDF, is the owner-operator of the closed and operational AGRs. This ownership is scheduled to be transferred to the NDA after the reactors have been defueled, with the first transfer possibly occurring "as early as 2026".[1184] While the legacy fleet is financed directly from the state budget, AGR decommissioning is to be paid for by the Nuclear Liabilities Fund (NLF). The NLF has however been underperforming for years and received substantial cash injections from the U.K. Government totaling £10.7 billion (US$$_{2023}$13.5 billion) between 2020 and 2022, making up half of the fund volume.[1185] In 2021, EDF's estimate for the undiscounted costs to decommissioning all seven AGR plants and the Sizewell B PWR was £23.5 billion (US$$_{2021}$32.32 billion), of which 13 to 34 percent were allocated to defueling alone. A 2022-report by the National Audit Office (NAO) raises concerns regarding the possible future necessity of additional taxpayer funding and potential lack of incentives for EDF to defuel the reactors swiftly and efficiently before transferring them to NDA custody.[1186] All six closed AGRs at Dungeness B, Hinkley Point B and Hunterston B are currently being defueled.[1187]

United States

The U.S. has not only the largest fleet of operating (93) and closed reactors but also the highest number of fully decommissioned units representing nearly three quarters of the global total.

1180 - NDA, "Business Plan—Financial year beginning April 2023 to financial year ending March 2026", SG/2023/34, Nuclear Decommissioning Authority, April 2023, p.26, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1151390/Business_Plan_2023-2026_-_final_for_web.pdf, accessed 23 June 2023.

1181 - NDA, "NDA Strategy - Effective from March 2021", Nuclear Decommissioning Authority, March 2021, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/973438/NDA_Strategy_2021_A.pdf, accessed 26 July 2023.

1182 - NDA, "Business Plan—Financial year beginning April 2023 to financial year ending March 2026", April 2023, op. cit.

1183 - *WNN*, "Berkeley decommissioning work brought forward 50 years", *World Nuclear News*, 11 May 2023, see https://www.world-nuclear-news.org/Articles/Berkeley-decommissioning-work-brought-forward-50-y?feed=feed, accessed 12 May 2023.

1184 - Committee of Public Accounts, "The future of the Advanced Gas-cooled Reactors—Third report of Session 2022-23", HC 118, House of Commons, 20 May 2022, see https://committees.parliament.uk/publications/22301/documents/165594/default/, accessed 26 July 2023.

1185 - NLF, "Fulfilling our purpose—Annual Report and Accounts 2022", Nuclear Liabilities Fund, 2023, see https://www.nlf.uk.net/uploads/images/31-March-2022-Annual-Report-interactive.pdf, accessed 31 March 2022.

1186 - NAO, "The decommissioning of the AGR nuclear power stations", HC 1017, National Audit Office, Department for Business, Energy & Industrial Strategy, 28 January 2022, see https://www.nao.org.uk/wp-content/uploads/2022/01/The-decommissioning-of-the-AGR-nuclear-power-stations.pdf, accessed 12 September 2023.

1187 - EDF, "Consolidated Financial Statements at 31 December 2022", February 2023, op. cit.

In the U.S., so far, 41 reactors (20 GW) have been closed.[1188] By 2050, at least 91 additional reactors are likely to undergo decommissioning if all units did reach licensed operational lifetimes (see Figure 50). Of the 41 already closed units (21 PWR, 14 BWR, 2 HTGR, 1 FBR, 1 PHWR, 2 others)[1189], 17 or 7.1 GW have been decommissioned. Currently, decommissioning work is ongoing at 12 units:

- Five reactors are in the warm-up stage: Indian Point-2, Kewaunee, San Onofre-2 & -3, and Three Mile Island-2 (all defueled).
- Five reactors are in the hot-zone stage: Crystal River-3, Fort Calhoun-1, Indian Point-3, Oyster Creek and Pilgrim-1.
- Two reactors are in the ease-off stage: San Onofre-1 and Vermont Yankee.

Since mid-2022, some progress has been made in U.S. decommissioning efforts. Most notably, two reactors moved to the hot-zone stage (Crystal River-3 and Indian Point-3), while one reactor (Vermont Yankee) has moved on to the ease-off-stage after work on the reactor internals was completed.

While decommissioning work at Zion-1 and -2 was completed in 2020, both reactors are still awaiting delicensing decisions by the NRC for unrestricted use.[1190]

The boiling water reactor at LaCrosse, having been technically decommissioned in 2019, was released from NRC oversight in February 2023. An interim storage facility for spent fuel remains onsite.[1191]

Three Mile Island-2 (TMI-2), where parts of the reactor core melted in the U.S.' worst commercial nuclear accident in 1979, has entered the warm-up stage. TMI-2 had been in LTE for the past 30 years. The reactor is counted as defueled as "99% of the spent nuclear fuel was cleaned up after the accident".[1192] Current owner EnergySolutions had via its subsidiary TMI-2 Solutions taken over the license with the intention of pulling the decommissioning completion date forward to 2037 instead of initial 2053.[1193] However, TMI-2 Solutions currently plans to terminate the site's nuclear license by 2052 due to "current market conditions" that necessitate a delay in fund withdrawals (and consequentially decommissioning progress) "from 2029 to 2045 as a financial mitigation measure for the [fund]".[1194] TMI-1 operated until 2019 and

1188 - Another closed reactor is GE ESADA Vallecitos Experimental Superheat Reactor (EVESR), which is next to the GE Vallecitos BWR. Although, the reactor never produced electricity, the site was not decommissioned but has been put into LTE. U.S. NRC, "Status of the Decommissioning Program—Annual Report", 2018.

1189 - PWR: Pressurized Water Reactor; BWR: Boiling Water Reactor; HTGR: High-Temperature Gas-Cooled Reactor; FBR: Fast Breeder Reactor; PHWR: Pressurized Heavy-Water Reactor.

1190 - U.S. NRC, "Status of the Decommissioning Program—2022 Annual Report—Enclosure 1", Division of Decommissioning, Uranium Recovery, and Waste Programs, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, December 2022, see https://www.nrc.gov/docs/ML2228/ML22286A050.pdf, accessed 19 June 2023.

1191 - U.S. NRC, "Power Reactor Sites—La Crosse Boiling Water Reactor", U.S. Nuclear Regulatory Commission, Updated 15 March 2023, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/lacrosse-boiling-water-reactor.html, accessed 19 June 2023.

1192 - Rachel McDevitt, "Three Mile Island enters new phase of cleanup", *State Impact Pennsylvania*, *NPR*, 11 May 2023, see https://stateimpact.npr.org/pennsylvania/2023/05/11/tmi-enters-new-phase-of-cleanup/, accessed 19 June 2023.

1193 - U.S. NRC, "Three Mile Island - Unit 2", United States Nuclear Regulatory Commission, 1 May 2023, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/three-mile-island-unit-2.htm, accessed 12 September 2023.

1194 - TMI-2 Solutions, "Decommissioning Fund Status Report – Three Mile Island, Unit 2", addressed to U.S. Nuclear Regulatory Commission, 30 March 2023, see https://www.nrc.gov/docs/ML2309/ML23094A116.pdf, accessed 12 September 2023.

was placed into LTE with actual decommissioning to last from 2075 2079. Spent fuel will be kept in dry storage until 2035 and will then be moved to a currently non-existent consolidated storage facility.[1195] The reactor itself was completely defueled in September 2019.[1196]

Crystal River-3 was closed in 2009 and placed into LTE, with dismantling to begin in 2067. In 2020, Accelerated Decommissioning Partners (ADP), a joint venture of NorthStar and French state-owned company Orano, acquired the license of the plant and began decommissioning the reactor. It is currently in the hot-zone stage, with reactor internal segmentation having been completed in late 2022 by applying a novel "Optimized Segmentation Process". Hot-zone tasks are expected to be completed in 2023 once all other reactor structures have been removed.[1197] The unit is expected to be fully decommissioned by 2037.[1198]

Decommissioning at Vermont Yankee, also conducted by ADP after moving forward beginning of work from an originally planned start date in 2069,[1199] has moved to the ease-off stage, as reactor dismantling was completed in December 2022, eight years after it last generated power. Decommissioning is expected to be completed by 2027.[1200] Previous WNISR editions had erroneously classified Vermont Yankee to be in the warm-up stage.

Prior to the acquisition of Oyster Creek by Holtec, utility Exelon had opted for deferred dismantling.[1201] In 2018, Holtec decided to directly dismantle the site,[1202] and was able to defuel the plant in 32 months.[1203] In parallel, several components were demolished, such as the air ejection off-gas building or the torus water storage tank.[1204] In April 2023, Holtec announced that the completion date for decommissioning had to be pushed back by four years to 2029, blaming economic conditions, such as increased labor costs.[1205] Whether this will also

1195 - U.S. NRC, "Power Reactor Sites—Three Mile Island Nuclear Station, Unit 1", United States Nuclear Regulatory Commission, Updated 15 January 2022, see https://www.nrc.gov/info-finder/reactors/tmi1.html; and Exelon Generation, "Three Mile Island Nuclear Station, Unit 1 - Post-Shutdown Decommissioning Activities Report", addressed to U.S. Nuclear Regulatory Commission, April 2019, see https://www.nrc.gov/docs/ML1909/ML19095A041.pdf; both accessed 5 November 2023.

1196 - Charles Thompson, "Removal of fuel assemblies from Three Mile Island Unit One reactor is complete; long storage period ahead", *PennLive*, 27 September 2019, see https://www.pennlive.com/news/2019/09/removal-of-fuel-assemblies-from-three-mile-island-unit-one-reactor-is-complete-long-storage-period-ahead.html, accessed 12 September 2023.

1197 - *WNN*, "New reactor dismantling technique used at Crystal River", *World Nuclear News*, 1 March 2023, see https://world-nuclear-news.org/Articles/New-reactor-dismantling-technique-used-at-Crystal, accessed 19 June 2023.

1198 - U.S. NRC, "Power Reactor Sites—Crystal River Unit 3 Nuclear Generating Plant", U.S. Nuclear Regulatory Commission, Updated 9 March 2023, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/cr3.html, accessed 25 July 2023.

1199 - TLG Services, "Vermont Yankee Nuclear Power Station (Draft)", 30 September 2014, see https://vydecommissioning.com/wp-content/uploads/2014/10/SAS-Appendix-C-Post-Shutdown-Decommissioning-Activities-Report-DRAFT.pdf, accessed 1 November 2023.

1200 - *WNN*, "Dismantling of Vermont Yankee reactor core completed", *World Nuclear News*, 14 December 2022, see https://world-nuclear-news.org/Articles/Dismantling-of-Vermont-Yankee-reactor-core-complet, accessed 19 June 2023.

1201 - Holtec Decommissioning International, "Notification of Revised Post-Shutdown Decommissioning Activities Report and Revised Site-Specific Decommissioning Cost Estimate for Oyster Creek Nuclear Generating Station", NRC Docket Nos. 50-219 and 72-15, 28 September 2018, see https://holtecinternational.com/wp-content/uploads/2021/02/HDI-PSDAR-DCE-ML18275A116.pdf, accessed 9 June 2022.

1202 - Ibidem.

1203 - *WNN*, "Oyster Creek defuelled in record time", *World Nuclear News*, 24 May 2021, see https://www.world-nuclear-news.org/Articles/Oyster-Creek-defuelled-in-record-time, accessed 9 June 2022.

1204 - *WNN*, "Decommissioning progresses apace at Oyster Creek and Pilgrim", *World Nuclear News*, 26 August 2021, see https://www.world-nuclear-news.org/Articles/Decommissioning-progresses-apace-at-Oyster-Creek-a, accessed 9 June 2022.

1205 - Amanda Oglesby, "Inflation leads Oyster Creek nuclear plant to delay decommissioning", *Asbury Park Press*, 5 April 2023, see https://eu.app.com/story/news/local/land-environment/2023/04/05/oyster-creek-nj-nuclear-plant-decommissioning-delayed/70081268007/, accessed 19 June 2023.

impact the envisioned license termination in 2035, estimated as of March 2022, has not been communicated.[1206]

Holtec is currently also decommissioning all three units at Indian Point. The 2019-plan envisions a partial license termination for the site (apart from on-site waste storage facilities) by 2033. Full license termination is planned for 2062.[1207] License transfer to Holtec was approved in 2020. The company has gone on to apply for "exemptions from certain emergency preparedness and planning requirements" that would reduce the "NRC's [...] requirements for the site to a level commensurate with the permanent cessation of operations and permanent removal of fuel from the reactor vessels [at Indian Point]". This application is still pending a final decision.[1208] At Unit 3, Holtec used "new HI-CUT segmentation technology" to begin dismantling reactor vessel internals. The technology is to be used at all three units of the plant.[1209]

Local residents are concerned about Holtec's plans to release 1.3–1.5 million gallons (4.9–5.7 million liters) of contaminated wastewater into the Hudson River. According to Holtec, the water contains "less than 400 Curies of tritium" (about 15 TBq).[1210] While Holtec says that the discharge of "monitored, processed, and treated water would not impact the environment or the health and safety of the public".[1211] New York Governor Kathy Hochul in August 2023 nonetheless signed a bill to halt the discharge into the Hudson.[1212]

The early closure of Palisades marks the latest reactor closure in the U.S. The plant was licensed to operate until 2031 but was taken off the grid in May 2022 after 50 years of operating lifetime.[1213] In June 2022, Holtec became the owner of the plant with plans to complete decommissioning it by 2041.[1214] By 10 June 2022, the plant was defueled. In July 2022 however, Holtec, together with

1206 - U.S. NRC, "Oyster Creek Nuclear Generating Station", United States Nuclear Regulatory Commission, Updated 23 March 2022, see https://www.nrc.gov/info-finder/reactors/oc.html, accessed 5 November 2023.

1207 - Holtec Decommissioning International, "Post Shutdown Decommissioning Activities Report including Site-Specific Decommissioning Cost Estimate for Indian Point Nuclear Generating Units 1, 2, and 3", addressed to U.S. Nuclear Regulatory Commission, 19 December 2019, see https://www.nrc.gov/docs/ML1935/ML19354A698.pdf, accessed 12 September 2023.

1208 - U.S. NRC, "Indian Point Nuclear Generating Unit 2", Updated 11 April 2021, United States Nuclear Regulatory Commission, 2 March 2023, see https://www.nrc.gov/info-finder/reactors/ip2.html, accessed 12 September 2023.

1209 - *NEI Magazine*, "Holtec uses new technology for dismantling work at Indian Point NPP", 10 January 2023, see https://www.neimagazine.com/news/newsholtec-uses-new-technology-for-dismantling-work-at-indian-point-npp-10503847, accessed 19 June 2023.

1210 - Rich Burroni, Presentation, on Behalf of Holtec Decommissioning International, 27 April 2023; see Department of Public Service of New York, "In the Matter of the Indian Point Closure Task Force and Indian Point Decommissioning Oversight Board", Transcript, Joint Meeting and Public Statement Hearing, filed 25 May 2023, see https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BC0015388-0000-C613-A53D-39FF2699B7CF%7D, accessed 17 November 2023.

1211 - Post-treatment tritium concentration levels in water from spent fuel pools of Indian Point-1 measured in September 2008 show levels of 0.447 µCi/liter (microcurie per liter). The official maximum tritium concentration for safe drinking water lies at 20 µCi per liter. Water discharge into the Hudson had been ongoing for decades before, leading to no measurable increase in tritium concentration; see Dave Lochbaum, "Tritium Disposal Options and Their Risks", filed with the New York State Department of Public Service, May 2023, see https://dps.ny.gov/system/files/documents/2023/05/disposal-options-and-risks-may-2023.pdf; and U.S. NRC, "Backgrounder on Tritium, Radiation Protection Limits, and Drinking Water Standards", United States Nuclear Regulatory Commission, April 2019, see https://www.nrc.gov/docs/ML0620/ML062020079.pdf, both accessed 12 September 2023.

1212 - Michael Hill, "New York governor blocks discharge of radioactive water into Hudson River from closed nuclear plant", *The Associated Press*, 18 August 2023, see https://apnews.com/article/indian-point-hudson-river-nuclear-pollution-2c8d0f5d31acc701bbc41bdb573bfac5, accessed 12 September 2023.

1213 - WNISR, "Palisades Reactor in the Closes Nine Years Early", World Nuclear Industry Status Report, 21 May 2022, see https://www.worldnuclearreport.org/Palisades-Reactor-in-the-US-Closes-Nine-Years-Early.html, accessed 25 July 2023.

1214 - *NEI Magazine*, "US Palisades NPP permanently closes ahead of schedule", 23 May 2022, see https://www.neimagazine.com/news/newsus-palisades-npp-permanently-closes-ahead-of-schedule-9717239, accessed 24 June 2022; *WNN*, "Palisades sale from Entergy to Holtec completed", *World Nuclear News*, 29 June 2022, see https://www.world-nuclear-news.org/Articles/Palisades-sale-from-Entergy-to-Holtec-completed, accessed 4 July 2022.

Governor of Michigan Gretchen Whitmer submitted a funding application to the Department of Energy's Civil Nuclear Credit program to restart operations at Palisades as, according to Holtec, "the repowering of Palisades is of vital importance to Michigan's clean energy future." After the first bid was declined in November, Holtec announced in December 2022 that they would reapply.[1215] By March 2023, it had become clear that Holtec is planning to apply for US$1 billion under a different federal funding program, and another US$300 million of state funding, to refurbish the plant and hire staff. In the meantime, decommissioning work has been halted.[1216] (See United States Focus).

For the time being, decommissioning remains the responsibility of the operators, who tender out some of the work to specialized companies, especially in the hot-zone stage.[1217] It seems, however, that the new organizational model of selling the license to a decommissioning contractor (identified in WNISR2018) is becoming increasingly popular and may even accelerate decommissioning (see WNISR2020 for more details). This new method consists of transferring the decommissioning license from the operator to a decommissioning contractor, mostly a waste management company, with the goal of reaping efficiency gains through the co-management of the decommissioning process by a company that owns disposal facilities. However, it is unclear whether this organizational model will resolve financing issues or end up in the socialization of costs in the end (see also Nuclear Economics and Finance).[1218]

CONCLUSION ON REACTOR DECOMMISSIONING

Assuming a 40-year average operational lifetime—the current world fleet average age is just over 31 years—a further 138 reactors will have been closed by 2030 (reactors connected to the grid between 1983 and 1990); and an additional 149 will be closed by 2063. This does not even account for the 120 reactors which have been operating for 41 years and longer, an additional 31 reactors in Long-term Outage (LTO), and the 58 reactors under construction as of mid-2023. As was shown in previous issues of WNISR that financial and technical challenges of reactor decommissioning are often underestimated. With more and more reactors reaching the end of their lifetimes, this underestimation will likely bring costly consequences.

Since WNISR2022, eight additional reactors (8 GW) have been closed: three in Germany, two each in the U.K. and Belgium and one in Taiwan. At most of these sites, preparations for decommissioning work are still underway.

Worldwide, as of mid-2023, 212 nuclear power reactors have been closed, exceeding for the first time 100 GW of permanently retired capacity. Only 22 have been fully decommissioned,

1215 - *WNN*, "Holtec to reapply for funding to restart Palisades", *World Nuclear News*, 20 December 2022, see https://world-nuclear-news.org/Articles/Holtec-to-reapply-for-funding-to-restart-Palisades, accessed 19 June 2023.

1216 - John Flesher, "Company seeks first-time restart of shuttered nuclear plant", *The Associated Press*, 26 April 2023, see https://apnews.com/article/palisades-nuclear-power-biden-whitmer-55019ca6d17c2b1965cae0de2f3a6235, accessed 25 July 2023.

1217 - Conrad Cooke and Holger Spann, "Reactor vessel internals segmentation at Zion", *Nuclear Engineering International*, 20 September 2013, see http://www.neimagazine.com/features/featurereactor-vessel-internals-segmentation-at-zion/; and AREVA, "Decommissioning & Dismantling", 2018, see http://us.areva.com/EN/home-3783/orano-usa-decommissioning--dismantling.html.

1218 - Rebecca Lordan-Perret, Robert D. Sloan and Robert Rosner, "Decommissioning the U.S. nuclear fleet: Financial assurance, corporate structures, and bankruptcy", *Energy Policy*, Vol. 154, July 2021, see https://linkinghub.elsevier.com/retrieve/pii/S030142152100149X, accessed 20 July 2022; and Muhammad Maladoh Bah, "Nuclear Decommissioning Profile USA", WWZ Working Paper 2023/02, Faculty of Business and Economics, University of Basel, January 2023, see https://edoc.unibas.ch/93044/, accessed 19 June 2023.

although some are still awaiting release from regulatory control, and only 8 of these have been returned to greenfield conditions, meaning the sites are available for unrestricted use. An additional 135 reactors are in some state of decommissioning with a further nine units in a post-operational status awaiting decommissioning, while 46 reactors are in a long-term enclosure (LTE) state.

In Europe, the 130 closed reactors represent more than 61 percent of the world's total and decommissioning efforts are advancing sporadically. With Germany having closed its last three operating nuclear power plants in April 2023, the country faces unprecedented parallel decommissioning of 27 reactors, with one additional reactor remaining in LTE and four more in a post-operational status. The U.K. is still implementing its new "lead-and-learn strategy" to its legacy fleet and is facing potential financial shortfalls for the decommissioning of its AGR fleet. According to French regulators, decommissioning are advancing to satisfyingly, although completion dates for ongoing projects are gradually pushed back year on year, and cost projections continuously rise.

The only countries to have fully decommissioned any commercial power reactors are the U.S. (17), Germany (4), and Japan (1). The latest addition to the list is the 63-MW BWR at Humboldt Bay, Illinois. This reactor was connected to the grid in 1963, closed in 1976 and has since then been undergoing decommissioning that was completed only in 2021. The machine generated power for 13 years, with decommissioning accomplished only 45 years after closure. Since WNISR2021, there has been no additional completed project.

Most of these decommissioned reactors are small, many of them are first generation designs, with an average capacity below 360 MW. On average, decommissioning work lasted for 20 years, sometimes years longer than operation.

Since WNISR2022, fifteen reactors have entered the warm-up stage, of which one each in Canada, Germany, and the U.S, two each in Belgium and Russia, and eight in the U.K., which is in the process of moving most of its legacy fleet from LTE to active decommissioning. 21 British reactors are thus in the warm-up stage, trumped only by 26 reactors in Japan, on the total of 89 reactors.

Three reactors moved from the warm-up to hot-zone stage, namely Grafenrheinfeld in Germany, and Crystal River-3 and Indian Point-3, both located in the U.S. Thus, 31 reactors are currently in the hot-zone stage, located in Germany (10), the U.K. (9), the U.S. (5), Sweden (4), France (2) and Italy (1).

Slovakian reactors Bohunice-1 and -2 advanced to the ease-off stage. This also goes for Vermont Yankee that erroneously had been previously classified as in the warm-up stage, but was, in fact, already undergoing hot-zone decommissioning. This places a total of 15 reactors in the ease-off stage. Germany leads this list with a total of nine reactors, followed by the U.S. and Slovakia with two each, and Spain and Belgium, with one each.

As no reactor has been placed into LTE since WNISR2022, the number of reactors in LTE has dropped from 52 in 2022 to 47 in 2023.

POTENTIAL NEWCOMER COUNTRIES

This chapter provides an overview of the status of nuclear projects in countries already in the course of building their first power reactors (Bangladesh, Egypt, Turkey), those who have more or less concrete plans to do so but so far neither selected a design nor assured a financing package (Kazakhstan, Nigeria, Saudi Arabia, Uzbekistan), and a group of countries that has cancelled or suspended previous plans (Indonesia, Jordan, Thailand, Vietnam). Poland is subject to a case study in the Focus Countries chapter.

Bangladesh

Bangladesh continues to build two Russian designed VVER-1200 nuclear reactors at Rooppur; construction of the two units began in November 2017 and July 2018, respectively.[1219] In July 2018, Rosatom announced that commercial operations were to commence in 2023 and 2024 respectively.[1220]

These deadlines are unlikely to be met, in part because of Russia's attack on Ukraine and resulting sanctions. For example, the German company Siemens refused to supply the gas-insulated switchgear needed for the project; Bangladesh then had to select a Chinese firm to supply the necessary equipment.[1221] Sanctions also means, as Rosatom itself acknowledged in March 2023, "no ship carrying cargo for the Rooppur Nuclear Power Plant can enter Bangladeshi waters".[1222] So far cargo has been shipped through India, with customs clearance being carried out in India and then the goods reshipped to Bangaldesh.[1223] Rooppur is a clear example where sanctions have impacted construction.

In December 2022, Bangladesh's Planning Minister announced that the installation of "the physical protection system (PPS) of the Rooppur nuclear power plant has been extended by one year and nine months".[1224] Likewise, in April 2023, Rooppur Project Director Muhammad Shawkat Akbar indirectly admitted that the project was delayed, when he told the

1219 - Rosatom, "First concrete poured at the constructed Rooppur NPP site (Bangladesh)", 30 November 2017, see https://rosatomafrica.com/en/press-centre/news/first-concrete-poured-at-the-constructed-rooppur-npp-site-bangladesh/, accessed 29 July 2023; and Rosatom, "Main construction of the 2nd Unit of Rooppur NPP begins with the 'First Concrete' ceremony", Press Release, 14 July 2018, see http://rosatom.ru/en/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-npp-begins-with-the-first-concrete-ceremony/, accessed 16 July 2018.

1220 - Rosatom, "Main Construction of the 2nd Unit of Rooppur NPP Begins with the 'First Concrete' Ceremony", July 2018, op. cit.

1221 - Eyamin Sajid, "Rooppur power generation to get delayed until July 2024", *The Business Standard*, 29 December 2022, see https://www.tbsnews.net/bangladesh/energy/rooppur-npp-commissioning-unit-1-get-delayed-least-6-months-559702, accessed 29 July 2023.

1222 - Rosatom, "Cooperation in Nuclear Energy", Rosatom Newsletter #3 (263), March 2023, see https://rosatomnewsletter.com/wp-content/uploads/2023/03/newsletter_03_263_eng_main.pdf, accessed 29 September 2023.

1223 - Rosatom, "Newsletter #263—March 2023—Strength Test Passed", Rosatom Newsletter #263, March 2023, see https://rosatomnewsletter.com/2023/03/22/strength-test-passed/, accessed 29 September 2023.

1224 - Rejaul Karim Byron, "Rooppur Nuke Power Plant: Launching not before 2025", *The Daily Star*, 22 March 2023, see https://www.thedailystar.net/news/bangladesh/news/rooppur-nuke-power-plant-launching-not-2025-3277196, accessed 29 July 2023.

press that "hopefully, Unit 1 will be commissioned in September 2024".[1225] Further, even as Rosatom dismissed fears about delays, it now talks about commissioning the plant in 2025 or earlier.[1226]

Alongside these delays, there are also reports that the project's cost, reported as US$12.6 billion in 2017,[1227] might "rise due to slow progress in power grid upgrade, possible changes in the loan repayment method amid the Russia-Ukraine war and the devaluation of the taka."[1228] In April 2023, the Bangladesh Finance Ministry "approved payment of [US]$318m for payment to Russia in the Chinese currency of yuan for construction of the Rooppur NPP".[1229] Earlier in September 2022, the Central Bank of Bangladesh allowed "local banks to open accounts in yuan in their branches abroad for settlements on cross-border transactions in Chinese currency".[1230] There have been problems with loans from Russia even prior to start of construction. One problem has been "servicing a [US]$500 million loan taken in 2013 from Russia for the Rooppur project's primary work" because the initial work around agreed upon—paying in Chinese currency—might not be an option after the latest round of sanctions; in turn, stuck payments raise the risk of Bangladesh "being classed as a defaulter" of a foreign loan.[1231]

Despite a number of studies showing the potential of renewables to provide energy economically,[1232] Bangladesh's installed capacity of renewables at the end of 2022 was only 775 MW, about 8 percent over the figure of 718 MW at the end of 2021, and about double the capacity a decade ago.[1233] Part of the problem is a lack of investment; for example, in the proposed FY2023–24 budget there were no specific incentives for clean energy.[1234] In the updated Nationally Determined Contribution from 2021 that Bangladesh submitted to the UNFCCC, the country listed implementing 911.8 MW of renewables by 2030 as part of its

1225 - Rosatom, "Accelerating Towards Launch", Newsletter #264, April 2023, see https://rosatomnewsletter.com/2023/04/27/accelerating-towards-launch/, accessed 29 July 2023.

1226 - *The Daily Star*, "Rooppur power plant runs into further snag", 28 April 2023, see https://www.thedailystar.net/news/bangladesh/diplomacy/news/rooppur-power-plant-runs-further-snag-3305941, accessed 13 May 2023.

1227 - *NIW, "Bangladesh", Nuclear Intelligence Weekly, 1 December 2017.*

1228 - Rejaul Karim Byron, "Rooppur nuclear power plant: Cost may rise for multiple factors", *The Daily Star*, 25 October 2022, see https://www.thedailystar.net/news/bangladesh/news/rooppur-nuclear-power-plant-cost-may-rise-multiple-factors-3151171, accessed 29 July 2023.

1229 - *NEI Magazine*, "Bangladesh pays Russia in Yuan for NPP to avoid sanctions", *Nuclear Engineering International*, 21 April 2023, see https://www.neimagazine.com/news/newsbangladesh-pays-russia-in-yuan-for-npp-to-avoid-sanctions-10779590, accessed 24 April 2023.

1230 - Ibidem.

1231 - *The Daily Star*, "Rooppur power plant runs into further snag", 28 April 2023, see https://www.thedailystar.net/news/bangladesh/diplomacy/news/rooppur-power-plant-runs-further-snag-3305941, accessed 13 May 2023.

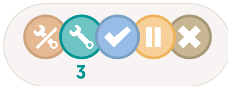
1232 - Ashish Gulagi, Manish Ram et al., "Current energy policies and possible transition scenarios adopting renewable energy: A case study for Bangladesh", LUT University, published in *Renewable Energy*, Vol 155, 1 August 2020, see https://www.sciencedirect.com/science/article/pii/S0960148120304511; and A. Z. A Saifullah, Md Abdul Karim and Md Raisul Karim, "Wind Energy Potential in Bangladesh", International University of Business, Agriculture and Technology, Dhaka University of Engineering and Technology, published in *American Journal of Engineering Research*, Vol. 5-7, 1 January 2016, see https://www.ajer.org/papers/v5(07)/K0507085094.pdf; both accessed 29 July 2023

1233 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf?rev=b357baf054584e589c8ab63514 0d0596, accessed 23 March 2023.

1234 - Eyamin Sajid, "Budget lacks initiatives to overcome energy crisis", *The Business Standard*, 1 Jun 2023, see https://www.tbsnews.net/economy/budget/budget-lacks-initiatives-overcome-energy-crisis-642466; and *Bangladesh Sangbad Sangstha*, "Tk 34,819cr proposed for power and energy", *National News Agency of Bangladesh*, 1 June 2023, see https://www.bssnews.net/national-budget-2023-2024/128594; both accessed 29 July 2023.

"unconditional contribution"; most of these sources is expected to be solar energy (581 MW), followed by wind power (149 MW), with no mention of nuclear energy.[1235]

Egypt



El Dabaa, Egypt's first nuclear power plant, is located on its north-west coast and is to host four VVER-1200 reactors. The project is being implemented by Russia's state-owned company Rosatom and its subsidiaries; according to a 2017 report, it is estimated to cost US$30 billion.[1236] Russia is lending Egypt US$25 billion for the project.[1237] Three of these units had first nuclear concrete poured in 2022 and early 2023: Unit 1 in July 2022, Unit 2 in November 2022, and Unit 3 in May 2023.[1238] The Egyptian Nuclear Power Authority is expected to issue the necessary permit for Unit 4 later in 2023,[1239] and Rosatom has announced that it plans for the "first concrete pouring for Unit 4" in "the last quarter of" 2023.[1240]

Previous WNISR issues have described the long history of Egypt's nuclear ambitions, beginning in the 1950s. The El Dabaa site was selected in the early 1980s.[1241] The current project derives from a contract signed by Russia and Egypt in 2017.[1242] At that time, Rosatom stated that Unit 1 was to be commissioned in 2026, and the entire project was to be completed by 2028–29.[1243] In May 2022, the head of Egypt's Nuclear Power Plants Authority (NPPA) stated that the first reactor will start operating "in 2028", the "second reactor in 2029", and the whole "plant will be fully operational in 2030".[1244] Other announcements have also mentioned a 2031 completion

1235 - Government of Bangladesh, "Nationally Determined Contributions (NDCs) 2021—Bangladesh (Updated)", August 2021, see https://www.undp.org/bangladesh/publications/nationally-determined-contributions-2021-bangladesh, accessed 19 August 2023.

1236 - Phil Chaffee, "Rosatom Locks in $30 Billion Nuclear Deal in Egypt", *Nuclear Intelligence Weekly*, 15 December 2017.

1237 - Asma Alsharif, "Russia to lend Egypt $25 billion to build nuclear power plant", *Reuters*, 1 May 2016, see https://www.reuters.com/article/us-egypt-russia-nuclear/russia-to-lend-egypt-25-billion-to-build-nuclear-power-plant-idUSKCN0YA1G5, accessed 24 April 2018.

1238 - Phil Chaffee and Jessica Sondgeroth, "First Nuclear Concrete at El-Dabaa-1, Akkuyu-4", *Nuclear Intelligence* Weekly, 22 July 2022; and *NEI Magazine*, "First concrete poured for unit 2 of Egypt's El-Dabaa NPP", 22 November 2022, see https://www.neimagazine.com/news/newsfirst-concrete-poured-for-unit-2-of-egypts-el-dabaa-npp-10376585/, accessed 29 November 2022; also Rosatom, "Main Construction Phase for Unit 3 of El-Dabaa Nuclear Power Plant Commences in Egypt", Press Release, 3 May 2023, see https://www.rosatom.ru/en/press-centre/news/main-construction-phase-for-unit-3-of-el-dabaa-nuclear-power-plant-commences-in-egypt/, accessed 7 May 2023.

1239 - *NEI Magazine*, "Egyptian regulator approves first concrete for El-Dabaa 4", 15 August 2023, see https://www.neimagazine.com/news/newsegyptian-regulator-approves-first-concrete-for-el-dabaa-4-11074750, accessed 15 August 2023.

1240 - Rosatom, "Successful Inspection Visit for Unit 4 of the El-Dabaa Nuclear Power Plant Site in Egypt", 2 August 2023, see https://rosatom-europe.com/press-centre/news/successful-inspection-visit-for-unit-4-of-the-el-dabaa-nuclear-power-plant-site-in-egypt/, accessed 21 August 2023.

1241 - Joy Nasr and Ali Ahmad, "Middle East Nuclear Energy Monitor: Country Perspectives 2018", Energy Policy and Security Program, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, January 2019, see https://www.aub.edu.lb/ifi/Documents/publications/research_reports/2018-2019/20190103_middle_east_nuclear_energy_monitor_country_perspectives_2018.pdf, accessed 30 July 2023.

1242 - *NEI Magazine*, "Egypt signs contract for El Dabaa", Nuclear Intelligence Weekly, 12 December 2017, see https://www.neimagazine.com/news/newsegypt-signs-contract-for-el-dabaa-6000526, accessed 29 July 2021.

1243 - Ibidem.

1244 - *EgyptToday*, "Egypt's Nuclear Plants Authority, Rosatom committed to Dabaa plant construction schedule: Official", 9 May 2022, see https://www.egypttoday.com/Article/3/115597/Egypt's-Nuclear-Plants-Authority-Rosatom-committed-to-Dabaa-plant-construction, accessed 17 July 2022.

date for the whole project.[1245] In June 2023, Egypt's Minister of Electricity and Renewable Energy, announced that the project "is expected to be completed between 2028 and 2031".[1246]

The Egyptian government appears to be eager to overcome past delays. In October 2022, the Energy and Environment Committee of Egypt's House of Representatives approved legislative amendments aimed at speeding up construction, and which changed NPPA's name to Nuclear Power and Renewable Energy Plants Authority, which is to become the sole owner and operator of nuclear power and renewable energy plants in Egypt.[1247] The bill was approved in Parliament in May 2023.[1248] In June 2023, a parliamentary committee approved Egypt joining the Convention on Nuclear Safety.[1249] Earlier, on 25 August 2022, Russia's Atomstroyexport entered into a US$2.25 billion-contract with South Korea's Korea Hydro and Nuclear Power (KHNP) to "provide certain materials and equipment and construct turbine buildings and other structures".[1250] Apart from a slight delay relating to the contract with KHNP, there appears to be no significant delays to the Dabaa project due to Russia's invasion of Ukraine.

Egypt's renewable energy capacity has grown slowly over the past decade, from 3.5 GW in 2013 to 6.3 GW in 2022. During this period, wind energy capacity has tripled to reach 1.6 GW in 2022, while solar energy capacity has shot up, from 35 MW in 2013 to 1.7 GW in 2022. [1251] Non-hydro renewables contributed 10.2 TWh (gross) in 2022, around 5 percent of the total electrical energy in Egypt's grid, whereas close to 80 percent of the electricity was produced by natural gas plants.[1252] In 2019, Egypt announced that by 2035 it plans to have 61 GW of renewable capacity installed, with 31 GW solar PV, 12 GW of Concentrated Solar Power, and 18 GW of wind power.[1253] By then, renewables are estimated to generate 42 percent of the total electricity in the country versus 3 percent supplied by nuclear.[1254]

1245 - Ibrahim Ayyad, "Ukraine war could delay Egypt's first nuclear power plant", *Al-Monitor*, 27 March 2022, see https://www.al-monitor.com/originals/2022/03/ukraine-war-could-delay-egypts-first-nuclear-power-plant, accessed 28 March 2022.

1246 - *Daily News Egypt*, "Dabaa nuclear plant project progresses according to schedule: Minister of Electricity", 14 June 2023, see https://www.dailynewsegypt.com/2023/06/14/dabaa-nuclear-plant-project-progresses-according-to-schedule-minister-of-electricity/, accessed 21 August 2023.

1247 - Gamal Essam El-Din, "Egypt MPs to vote on tax exemptions for contractors, workers building Dabaa's nuclear power plant", *Ahram Online*, 20 October 2022, see https://english.ahram.org.eg/News/478197.aspx, accessed 29 November 2022.

1248 - Gamal Essam El-Din, "Egypt parliament approves bill speeding completion of El-Dabaa nuclear plant", *Ahram Online*, 2 May 2023, see https://english.ahram.org.eg/NewsContent/1/1235/498886/Egypt/Urban--Transport/Egypt-parliament-approves-bill-speeding-completion.aspx, accessed 21 August 2023.

1249 - Gamal Essam El-Din, "A parliamentary committee approves Egypt joining IAEA's Convention on Nuclear Safety", *Ahram Online*, 14 June 2023, see https://english.ahram.org.eg/News/503042.aspx, accessed 30 July 2023.

1250 - Kim Tong-Hyung, "S Korea signs $2.25 billion deal with Russia nuclear company", *The Associated Press*, 25 August 2022, see https://apnews.com/article/russia-ukraine-middle-east-africa-349bf2b3eb2551bdea5ec886855dea92, accessed 29 November 2022.

1251 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

1252 - Energy Institute, "Statistical Review of World Energy 2023 - Data", with KPMG and Kearney, June 2023, see https://www.energyinst.org/__data/assets/excel_doc/0007/1055545/EI-stats-review-all-data.xlsx, accessed 30 July 2023.

1253 - Mohamed Farag, "How does Egypt plan to produce 42% of its electricity from renewables by 2035?", *Daily News Egypt*, 17 December 2019, see https://dailynewsegypt.com/2019/12/17/how-does-egypt-plan-to-produce-42-of-its-electricity-from-renewable-sources-by-2035/, accessed 10 July 2022.

1254 - NREA, "2022 Annual Report", New & Renewable Energy Authority, 2023, see http://nrea.gov.eg/Content/reports/Annual%20Report%202022%20Eng.pdf, accessed 2 September 2023.

Kazakhstan

Kazakhstan operated a small fast breeder reactor, the BN350 at Aktau, between 1973–1998 and is one of four countries in the world to have abandoned commercial nuclear power, the others being Germany, Italy, and Lithuania. But in contrast to the other countries Kazakhstan has considerable uranium reserves and, with Kazatomprom, has developed the world's largest producer. Kazakhstan has had discussions with countries and reactor suppliers over the years. In April 2019, during a meeting between President Putin of Russia and Kazakhstan's President Qasym-Zhomart Toqaev, it was suggested that Russia was to help in the construction of a nuclear power plant at Ulken, in the southeastern Almaty Province. Soon after this, Deputy Kazakh Energy Minister Magzum Mirzagaliev said there was no "concrete decision" to construct a nuclear power plant in Kazakhstan.[1255]

In January 2022, trade journal *Nuclear Intelligence Weekly* stated: "Tokayev [President Toqaev] will also step up plans to transform Kazakhstan into a green energy hub by attracting more investment into wind, solar and hydrogen projects. But what of the government's Kazakhstan Nuclear Power Plants (KNPP) and its plans to build a midsized power reactor?"[1256]

In February 2022, it was reported that the government was considering six suppliers for SMRs or large reactors: NuScale, GE Hitachi, China National Nuclear Corporation (CNNC), Rosatom and EDF. But in June 2022, NuScale and GE Hitachi were excluded from the process as their proposed technologies had not been implemented anywhere.[1257]

In April 2023, Almasadam Satkaliyev, Kazakhstan's Minister of Energy confirmed that «several applications are being considered. There is a French company, a Korean company, there are proposals from Chinese partners, there are proposals from Russian partners. When we consider construction experience and the number of units and efficient plants currently under construction in the world, then, with respect to the nuclear island Rosatom has a certain leadership." Kazakhstan has not decided whether to go ahead with the nuclear plan and, if yes, Satkaliyev indicated it might split the order into nuclear island, the electrical equipment, and grid system.[1258]

The IAEA has completed an Integrated Nuclear Infrastructure Review (INIR) mission in March 2023, a follow-up to an initial 2016 mission. "Kazakhstan has made considerable effort to address the recommendations and suggestions made by the INIR team in 2016, which includes the preparatory work to inform the Government's decision on whether to introduce a nuclear power program," the mission's team leader stated.[1259]

1255 - Bruce Pannier, "Putin Offers Russian Help To Build Kazakh Nuclear Plant", *RadioFreeEurope/RadioLiberty*, 6 April 2019, see https://www.rferl.org/a/kazakhstan-putin-offers-russian-nuclear-plant-help/29865177.html, accessed 1 May 2021.

1256 - *NIW*, "Kazakhstan – As Faultlines Exposed, Uranium Production Proceeds", *Nuclear Intelligence Weekly*, 14 January 2022.

1257 - *WNN*, "Kazakh, Korean companies to cooperate in nuclear power projects", *World Nuclear News*, 29 June 2022, see https://www.world-nuclear-news.org/Articles/Kazakh,-Korean-companies-to-cooperate-in-nuclear-p, accessed 29 August 2022.

1258 - *NEI Magazine*, "Kazakhstan continues to pursue NPP plans", *Nuclear Engineering International*, 13 April 2023, see https://www.neimagazine.com/news/newskazakhstan-continues-to-pursue-npp-plans-10756528, accessed 7 October 2023.

1259 - IAEA, "IAEA Reviews Progress of Kazakhstan's Nuclear Infrastructure Development", International Atomic Energy Agency, 2023, see https://www.iaea.org/newscenter/pressreleases/iaea-reviews-progress-of-kazakhstans-nuclear-infrastructure-development, accessed 7 October 2023.

Nigeria

When in early 2023 Nigeria launched its Energy Transition Plan (ETP) with the goal of carbon neutrality by 2060, observers were surprised that nuclear power did not feature amongst the options outlined for electricity generation.[1260] The ETP sets very ambitious targets for centralized solar, going from virtually nothing currently to 8 GW in 2030, 81 GW in 2040 to 197 GW in 2050 then representing three quarters of the installed capacity. Centralized storage is to be boosted to 35 GW by 2040 and 90 GW in 2050 complemented by a 22 GW electrolizer capacity for hydrogen production. Decentralized systems are to be developed in parallel to progressively replace 5.3 GW of oil and gas fired generators. The main components are microgrids, solar home systems, and solar-plus-battery systems that are to contribute respectively 2.6 GW, 1.8 GW and 1.9 GW by 2030 and 7 GW, 5.2 GW, and 3.5 GW by 2050.[1261]

For years, the Nigerian administration and various national institutions have strongly supported the idea of the implementation of a national nuclear power program. In November 2019, the Senate called on the Government to consider including nuclear power in the power mix to give a mandate to the Atomic Energy Commission to negotiate with international nuclear vendors. Nigeria has previously sought the support of the IAEA to develop plans for up to 4 GW of nuclear capacity by 2025, which are obviously not achievable in the originally envisaged timeframe.[1262] In March 2022, the Director General of the Nigerian Nuclear Regulatory Authority (NNRA), Yau Idris, said that "Nigeria is trying to deliver 4,000 MW of electricity through nuclear power. We are planning to construct four units and currently we are at the bidding phase of the nuclear power program in Nigeria." He added that agreements relating to the power plant project had been signed with South Korea, France, Russia, and India, and that the NNRA also had agreements on cooperation and training with regulators in the U.S., Pakistan, South Korea, and Russia.[1263]

A conference organized in July 2022 by the Heinrich Böll Foundation and the Electricity Hub in Abuja, Nigeria,[1264] saw the former Chairman of the Nigerian Electricity Regulatory Commission (NERC) pointing to the lack of adequate transmission infrastructure to manage even existing generation power and posed the question "whether the government should be more concerned with expanding capacity or increasing investments to ensure that the current generated capacity gets reliably distributed". The Co-founder/CTO of the Clean Technology Hub Nigeria suggested that the country did not appear ready for nuclear power generation "given the challenges around the existing electricity generation and supply network".[1265]

1260 - Ola Alokolaro, Uchechi Ibeku and Mary Oke, "Prospect for nuclear power development in Nigeria", *BusinessDay*, 23 March 2023, see https://businessday.ng/news/legal-business/article/prospect-for-nuclear-power-development-in-nigeria/, accessed 26 September 2023.

1261 - Nigerian Government, "Power – Nigeria Energy Transition Plan", Undated, see https://www.energytransition.gov.ng/power/, accessed 26 September 2023.

1262 - *WNN*, "Nigerian Senate calls for inclusion of nuclear in energy mix", *World Nuclear News*, 21 November 2019, see https://www.world-nuclear-news.org/Articles/Senate-calls-for-nuclear-inclusion-in-Nigeria-s-en, accessed 1 May 2021.

1263 - *WNN*, "Nigeria moving ahead on nuclear power plant plan", 18 March 2022, see

, accessed 18 March 2022.

1264 - The WNISR-Coordinator gave a presentation at the event.

1265 - *The Authority*, "Electricity Crisis: Experts at Nextier canvass for Nigeria's nuclear energy development", 3 August 2022, see https://authorityngr.com/2022/08/03/electricity-crisis-experts-at-nextier-canvass-for-nigerias-nuclear-energy-development/, accessed 4 August 2022.

Reportedly, President Mohammadu Buhari stated at a conference in Washington, D.C. in November 2022 that Nigeria would "explore nuclear energy to generate electricity". The Minister of Science, Technology and Innovation, Sen. Adeleke Mamora, stated

> With the Small Modular Reactor, SMR, technology evolving, Nigeria sees this as a future game-changer in the nuclear industry and looks forward to a greater engagement with the IAEA and other global partners in the coming months and years to discuss the possibility of deploying SMRs in the country.[1266]

On 27 July 2023, the daily *Vanguard* noted "Nigeria, the giant of Africa, was conspicuously absent… as African leaders gathered in St Petersburg, Russia, to discuss ways nuclear power can help solve the continent's perennial energy crisis." The meeting discussed "Nuclear technologies for the development of [the] African continent" at the high-level Russia-Africa Economic Forum in St Petersburg Russia. Panelists included Rosatom's Director General.[1267]

In continental Africa, only South Africa has an operating nuclear power plant (see South Africa Focus). This is despite repeated support from national governments and encouragement from international vendors, particularly China and Russia in recent times.

According to the World Nuclear Association (WNA), China has agreements with—but no plants under construction—Kenya and Sudan, while Russia signed agreements with Algeria, Congo, Egypt, Ethiopia, Ghana, Morocco, Nigeria, Rwanda, Sudan, Tunisia, Uganda, and Zambia.[1268] Egypt being the only country with active construction.

In September 2020, Russia signed a Memorandum of Understanding (MoU) for cooperation with the African Commission on Nuclear Energy (AFCONE), to establish a basis for Russia to help African countries with various projects related to nuclear energy.[1269] The vast majority of these are little more than political statements of support designed to increase diplomatic links with key infrastructure providers and recipients.

In spite of the multitude of agreements, few developments on nuclear activities in Africa reflect some significance on the ground.

Poland

See Focus Countries – Poland Focus.

1266 - Emmanuel Elebeke, "Nigeria'll explore nuclear energy to generate electricity — Buhari", *Vanguard News*, 7 November 2022, see https://www.vanguardngr.com/2022/11/nigeriall-explore-nuclear-energy-to-generate-electricity-buhari/, accessed 6 October 2023.

1267 - Prince Osuagwu, "Nigeria missing as Africa agrees nuclear energy is best alternative power source", *Vanguard News*, 27 July 2023, see https://www.vanguardngr.com/2023/07/nigeria-missing-as-africa-agrees-nuclear-energy-is-best-alternative-power-source/, accessed 6 October 2023.

1268 - WNA, "Emerging Nuclear Energy Countries", Updated October 2022, see https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx, accessed 17 October 2022.

1269 - *NEI Magazine*, "Russia to co-operate with Afcone", *Nuclear Engineering International*, 29 September 2020, see https://www.neimagazine.com/news/newsrussia-to-co-operate-with-afcone-8153681/, accessed 1 May 2021.

Saudi Arabia

Saudi Arabia has been interested in building nuclear power plants for over a decade and a half, establishing The King Abdullah City for Atomic and Renewable Energy (KA-CARE) in 2010.[1270] Progress has been slow, and Saudi officials no longer talk about early plans for establishing 18 GW of nuclear power capacity.[1271] It was only in May 2022 that KA-CARE invited bids to construct two nuclear reactors.[1272]

Earlier in 2023, the kingdom confirmed that it had received bids; the four builders that are most likely to have bid are Korea Electric Power Company (KEPCO), China National Nuclear Corporation (CNNC), Russia's state-owned Rosatom, and France's EDF.[1273] In December 2022, Russia's Deputy Prime Minister had confirmed that Russia did submit a bid, most likely for two VVER-1200 reactors.[1274]

In November 2022, South Korea's President Yoon Suk-yeol and Saudi Arabian Crown Prince Mohammed bin Salman talked about cooperating on nuclear energy during the latter's visit to Seoul.[1275] However, KEPCO's ability to supply those reactors will depend on the results of a lawsuit filed by Westinghouse against Korea Hydro and Nuclear Power (KHNP) and KEPCO in October 2022.[1276] According to Westinghouse, the APR-1400 reactor is based on the System-80 design, which was developed by Combustion Engineering; Westinghouse acquired Combustion Engineering in 2000. KHNP obtained an approval from the U.S. Department of Energy and subcontracting with Toshiba, then Westinghouse's owner, when it undertook the Barakah project in the UAE.[1277] Another challenge to KEPCO executing the Saudi project is its growing financial deficit; the severity of the problem led the KEPCO President and CEO to resign in May 2023.[1278]

One country that did not bid was the U.S. However, in June 2023, at a joint press conference with U.S. Secretary of State Antony Blinken, Saudi Arabia's foreign minister said the kingdom would prefer to have the U.S. as one of the bidders for its civilian nuclear program.[1279] It is not clear if this is a signal that the bidding process will be reopened. There is also the unresolved

1270 - Abdullah bin Abdul Aziz Al Saud, "Royal Decree establishing King Abdullah City for Atomic and Renewable Energy", Decree No A/35, 2010, see https://www.climate-laws.org/geographies/saudi-arabia/policies/royal-decree-establishing-king-abdullah-city-for-atomic-and-renewable-energy-2010, accessed 11 June 2021.

1271 - April Yee, "Saudi Arabia to seek bids for its first nuclear reactor", *The National*, 11 November 2013, see http://www.thenational.ae/business/industry-insights/energy/saudi-arabia-to-seek-bids-for-its-first-nuclear-reactor, accessed 16 November 2013.

1272 - Jung Suk-yee, "Nuclear Power Plant Project Anticipated in Saudi Arabia", *Business Korea*, 2 June 2022, see http://www.businesskorea.co.kr/news/articleView.html?idxno=93914, accessed 28 July 2022.

1273 - Phil Chaffee and Jessica Sondgeroth, "Vendors Line Up for Saudi Nuclear Plant", *Nuclear Intelligence Weekly*, 31 March 2023.

1274 - *NucNet*, "Russia Submits Bid for Saudi Arabia's Twin Nuclear Reactors", as published on *Neutron Bytes*, 18 December 2022, see https://neutronbytes.com/2022/12/18/russia-submits-bid-for-saudi-arabias-twin-nuclear-reactors/, accessed 30 July 2023.

1275 - Sarah Kim, "Yoon and Saudi crown prince agree on economic cooperation", *Korea JoongAng Daily*, 17 November 2022, see https://koreajoongangdaily.joins.com/2022/11/17/national/politics/Korea-Saudia-Arabia-summit/20221117184415158.html, accessed 30 July 2023

1276 - *NIW*, "Westinghouse Sues Kepco/KHNP", *Nuclear Intelligence Weekly*, 4 November 2022.

1277 - Jung Min-hee, "Westinghouse Files a Suit Against KHNP and KEPCO", *BusinessKorea*, 25 October 2022, see http://www.businesskorea.co.kr/news/articleView.html?idxno=102734, accessed 30 July 2023.

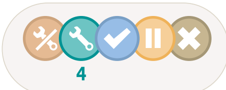
1278 - *The Korea Herald*, "Kepco chief offers to resign amid deficit woes", 12 May 2023, see https://news.koreaherald.com/common/newsprint.php?ud=20230512000550, accessed 13 May 2023.

1279 - Aziz El Yaakoubi and Humeyra Pamuk, "Saudi foreign minister: wants U.S. to bid in domestic nuclear programme", *Reuters, 8 June 2023, see* https://www.reuters.com/world/saudi-foreign-minister-wants-us-bid-domestic-nuclear-programme-2023-06-08/, accessed 15 June 2023.

dispute over Saudi Arabia's interest in enriching uranium, as a result of which the U.S. does not have a 123 agreement with the country.[1280] The U.S. Congress has "prohibited the use of appropriated funds for Export-Import Bank support for nuclear exports to Saudi Arabia until the kingdom has a 123 agreement 'in effect'; 'has committed to renounce uranium enrichment and reprocessing on its territory under that agreement'; and has 'signed and implemented' an Additional Protocol with the IAEA".[1281] Negotiating a 123 agreement between Saudi Arabia and the United States is tied up with a larger diplomatic plan for the Middle East, including Israeli-Saudi diplomatic relations, which in turn is related to Israel's treatment of the Palestinians and ongoing settler expansion in the occupied territories.[1282] A 123 agreement is also complicated by Saudi interest in uranium enrichment. The Congressional Research Service recently noted that allowing Saudi Arabia to enrich uranium would require amending the 123 agreement with the UAE because that agreement included a minute stating that its terms "shall be no less favorable in scope and effect than those which may be accorded" to other countries in the Middle East.[1283]

Total renewable energy capacity in Saudi Arabia has grown from 22 MW in 2013 to 443 MW in 2022, but there was no net capacity growth in the past year.[1284] Almost all of this capacity is in the form of solar energy; of the total of 440 MW of solar power capacity in 2022, solar photovoltaics constitute 390 MW and concentrated solar power accounts for the remaining 50 MW. Renewables contributed 0.8 TWh or 0.2. percent of the total electricity produced in the country in 2022.[1285] The remaining 99.8 percent came from natural gas (269.4 TWh) and oil (131.4 TWh). There are plans for expanding renewables, and in November 2022, a local utilities company "signed an agreement… to build the world's largest single-site solar-power plant… with a generation capacity of 2,060 MW".[1286] In all, an estimated 13 to 14 GW of solar energy and 5 GW of wind are said to be in the pipeline, although even that will not make a substantial difference to the country's reliance on fossil fuels.[1287]

Turkey



There are currently four nuclear reactors under construction in Turkey, the four VVER-1200 units at Akkuyu. The agreement to build Akkuyu, estimated at US$20 billion, was signed in

1280 - The name derives from Section 123 of the United States Atomic Energy Act of 1954, titled "Cooperation With Other Nations", which is a prerequisite for nuclear trade and other forms of cooperation between the United States and any other nation.

1281 - Paul K. Kerr and Christopher M. Blanchard, "Prospects for U.S.-Saudi Nuclear Energy Cooperation", Congressional Research Service, Updated 9 June 2023, see https://sgp.fas.org/crs/mideast/IF10799.pdf, accessed 30 July 2023.

1282 - Julian Borger, "US-Saudi talks amid reports of far-reaching diplomatic plan for Middle East", *The Guardian*, 27 July 2023, see https://www.theguardian.com/world/2023/jul/27/saudi-arabia-united-states-diplomatic-endeavor, accessed 26 August 2023.

1283 - Congressional Research Service, "Prospects for U.S.-Saudi Nuclear Energy Cooperation", June 2023, op. cit.

1284 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

1285 - Energy Institute, "Statistical Review of World Energy 2023—Data", June 2023, op. cit.

1286 - Lucia Garcia, "Saudi Arabia launches world's largest solar-power plant", *Economist Intelligence Unit*, 17 February 2023, see https://www.eiu.com/n/saudi-arabia-launches-worlds-largest-solar-power-plant/, accessed 26 August 2023.

1287 - Nick Ferris, "Will Saudi Arabia ever make good on its solar ambitions?", *Energy Monitor*, 3 May 2023, see https://www.energymonitor.ai/tech/renewables/will-saudi-arabia-ever-make-good-on-its-solar-ambitions/, accessed 26 August 2023.

2010, with projected startup dates of "between 2016 and 2019".[1288] As detailed in previous editions of the WNISR, the project has been delayed, and construction of the first unit began only in 2018.[1289] The other three units began construction in April 2020, March 2021, and July 2022.[1290]

When Rosatom started building the first unit, Russian President Putin said: "The first unit of Akkuyu NPP must be put online in 2023… I am sure that in 2023 entire Turkey will feel the feedback of the energy to be generated by this plant, this high-technology facility".[1291] The year 2023 marks 100 years since the founding of modern Turkey. The other three units were projected to start operating by 2025.[1292]

Rosatom missed the 2023 deadline. At the event in April 2023 to celebrate Rosatom delivering the first batch of nuclear fuel, Turkey's Minister of Energy and Natural Resources stated his "hope that next year the nuclear power plant will start generating electricity" and "add another source of energy to the country's energy sources".[1293] In June 2023, *Nuclear Intelligence Weekly* reported that Akkuyu-1 "now appears scheduled for commercial operation in 2025".[1294]

Turkey has long pursued nuclear projects at two other sites, Sinop and İğneada, but neither project has moved to the point of starting construction. However, Turkish officials continue to talk about starting work at these sites. In November 2022, Turkish President Recep Tayyip Erdogan said that Turkey is in talks with Rosatom on Sinop.[1295] And in January 2023, the Korea Electric Power Corporation submitted a preliminary proposal to construct four APR-1400 reactors at an undisclosed site in the northern part of the country.[1296] According to Korean officials, the first step might be a feasibility study, and the project is expected to cost US$$_{2022}$30.7 billion.[1297] The 2022 National Energy Plan published by Turkey's Ministry of Energy

1288 - *POWER Magazine*, "New Nuclear Projects for Turkey, Jordan, and Mexico—Mexico Considers Building 10 Nuclear Power Plants by 2028", 19 May 2010, see https://www.powermag.com/new-nuclear-projects-for-turkey-jordan-and-mexico/, accessed 1 June 2022.

1289 - *WNN*, "Russia starts building Turkey's first nuclear power plant", *World Nuclear News*, 3 April 2018, see http://www.world-nuclear-news.org/NN-Russia-starts-building-Turkeys-first-nuclear-power-plant-03041801.html, accessed 4 April 2018.

1290 - *Daily Sabah*, "Construction starts on 2nd unit of Turkey's 1st nuclear power plant Akkuyu", 28 June 2020, see https://www.dailysabah.com/business/energy/construction-starts-on-2nd-unit-of-turkeys-1st-nuclear-power-plant-akkuyu; and Rosatom, "Construction of Akkuyu NPP Unit 3 (Turkey) Begins", Press Release, 10 March 2021, see https://rosatom.ru/en/press-centre/news/construction-of-akkuyu-npp-unit-3-turkey-begins/; also Akkuy Nuclear, "Main Construction Phase Commences at Akkuyu NPP Unit 4 in Turkey", Press Release, 21 July 2022, see http://www.akkuyu.com/main-construction-phase-commences-at-akkuyu-npp-unit-4-in-turkey/update, all accessed 30 July 2023.

1291 - Rosatom, "Presidents of Russia and Turkey Vladimir Putin and Recep Tayyip Erdoğan kicked off large-scale construction of Akkuyu NPP", Press Release, 4 April 2018, see http://rosatom.ru/en/press-centre/news/presidents-of-russia-and-turkey-vladimir-putin-and-recep-tayyip-erdo-an-kicked-off-large-scale-const/, accessed 4 April 2018.

1292 - *WNN*, "Russia Starts Building Turkey's First Nuclear Power Plant", 3 April 2018, op. cit.

1293 - Akkuyu Nuclear, "First Batch of Fuel Delivered to Akkuyu NPP", Rosatom, 27 April 2023, see http://www.akkuyu.com/first-batch-of-fuel-was-delivered-to-akkuyu-npp/update, accessed 29 April 2023.

1294 - Grace Symes, "Akkuyu-1 Commissioning Pushed to 2025", *Energy Intelligence*, 9 June 2023, see https://www.energyintel.com/00000188-9c8c-dfa7-aded-9fcee6050000, accessed 26 June 2023.

1295 - *NEI Magazine*, "Turkey considers construction of third NPP", 8 November 2022, see https://www.neimagazine.com/news/newsturkey-considers-construction-of-third-npp-10273516/, accessed 4 July 2023.

1296 - *WNN*, "Korea proposes building four reactors for Turkey", *World Nuclear News*, 31 January 2023, see https://www.world-nuclear-news.org/Articles/Korea-proposes-to-build-four-reactors-for-Turkey, accessed 4 July 2023.

1297 - Park Eun-jee, "Korea's Kepco discussing nuclear project with Turkey", *Korea JoongAng Daily*, 15 December 2022, see https://koreajoongangdaily.joins.com/2022/12/15/business/industry/Korea-Turkey-nuclear-project/20221215181259875.html, accessed 4 July 2023.

and Natural Resources projects the "total installed capacity of nuclear power plants" to "reach 7.2 GW by 2035", out of a total of 189.7 GW.[1298]

Total renewable energy capacity in Turkey has grown over the past decade from 25.6 GW in 2013 to 56 GW in 2022, with an increase of 5.2 percent in the past year.[1299] Over half of the renewable capacity is hydropower, with 31.6 GW, but wind (11.4 GW) and especially solar (9.4 GW) have been growing rapidly. In 2022, non-hydro renewables contributed 21.9 percent of the total electrical energy generated in the country.[1300] The 2022 National Energy Plan envisions a total installed capacity of 29.6 GW of wind, 52.9 GW of solar, and 35.1 GW hydro by 2035. In terms of capacity additions, the majority (74.3 percent) is expected to come from renewables.

Uzbekistan

In 2017, Uzbekistan signed a framework nuclear cooperation agreement with Russia. In September 2018, a further agreement was signed for the construction by Rosatom of two VVER-1200 reactors with a combined capacity of 2.4 GW. As of 2020, they were expected to be commissioned in 2028 and 2030, respectively.[1301]

In an April-2019 interview with *Nuclear Engineering International* (*NEI*), Jurabek Mirzamakhmudov, Director General of Uzatom, announced site analysis work over the following 12–18 months at three locations. Mirzamakhmudov said that the investment would be partially financed through a soft loan from Russia. The reactors would provide power for domestic consumption, but some of it could also be exported to neighboring countries such as Afghanistan.[1302] It was later stated that the intention was to choose a site, and have it licensed by September 2020,[1303] which did not happen.

In May 2022, Mirzamakhmudov stated that a site had been chosen in the Farish district of the Jizzakh region, near Lake Tuzkan to host two Rosatom-supplied VVER-1200s. Mirzamakhmudov said in an interview that while the financing package were still under negotiation, recent Ukraine-related sanctions against Russia would have no impact on the process. He added that one of the reasons of delay were ongoing analysis whether to use "dry cooling" towers to save water uptake from Lake Tuzkan.[1304]

The IAEA carried out a Site and External Events Design Review Service (SEED) mission, which took place from 16 to 20 January 2023, and concluded that "Uzbekistan has carried

1298 - Ministry of Energy and Natural Resources, "Türkiye National Energy Plan", Turkish Government, 2022, see https://enerji.gov.tr/Media/Dizin/EIGM/tr/Raporlar/TUEP/T%C3%BCrkiye_National_Energy_Plan.pdf, accessed 26 August 2023.

1299 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

1300 - Energy Institute, "Statistical Review of World Energy 2023—Data", June 2023, op. cit.

1301 - *WNN*, "Uzbekistan's energy plans", *World Nuclear News*, 29 July 2020, see https://www.neimagazine.com/features/featureuzbekistans-energy-plans-8051183/, accessed 17 October 2023.

1302 - *NEI* Magazine, "Uzbekistan's nuclear aspirations", Interview with Jurabek Mirzamakhmudov, Director of Uzatom, 9 April 2019, see https://www.neimagazine.com/features/featureuzbekistans-nuclear-aspirations-7145738/, accessed 1 May 2021.

1303 - *WNN*, "Russia and Uzbekistan agree to start survey of new plant site", *World Nuclear News*, 17 May 2019, see https://www.world-nuclear-news.org/Articles/Russia-and-Uzbekistan-agree-to-start-survey-of-new, accessed 1 May 2021.

1304 - *NIW*, "Uzbekistan – Site Selected for First Nuclear Plant", *Nuclear Intelligence Weekly*, 1 July 2022.

out an objective and safety-oriented site characterization process". However, amongst the recommendations, there are some issues that seem rather basic like the advice to "identify and select feasible engineering measures to provide plant cooling and site protection from external events, with reference to the specific plant technology selected by the owner and the number of units."[1305]

SUSPENDED OR CANCELLED PROGRAMS

Indonesia

Indonesia is ranked sixteenth in terms of GDP and in 2022 was one of only five countries in the Top 20[1306] besides Australia, Germany, and Italy (that both have phased out their program) and Saudi Arabia, that have no active nuclear fleet and are not in the course of building their first plant (like Turkey).

In 1997, a Nuclear Energy Law was adopted that gave guidance on construction, operation, and decommissioning. After various attempts, in December 2015, the government pulled the plug on all nuclear plans, even for the longer-term future.

However, in July 2020, the U.S.-based nuclear company ThorCon International and Indonesia's Defense Ministry signed an MoU to "study developing a thorium molten salt reactor (TMSR) for either power generation or marine vehicle propulsion."[1307] In March 2023, ThorCon submitted a "consultation paper" to the Nuclear Power Regulatory Agency (Bapeten), seen as the beginning of the licensing process. The target date for commercial operation is 2032, very optimistic if not unrealistic if compared to experience with other new reactor designs.[1308]

Indonesia is thought to have considerable thorium reserves and researchers are looking at the extraction of uranium and thorium from unconventional sources, particularly monazite, which is often co-located with the country's tin ore. In 2020, Indonesia was the world's biggest tin producer and remained a top producer in 2022.[1309]

Plans of the Ministry of Energy aim for an ambitious 35 GW in nuclear power capacity to help achieve its net zero target by 2060,[1310] leaving much room for uncertainty on the future developments of these projects, the first question being whether the parliament will indeed approve the bill.

1305 - IAEA, "IAEA Team in Uzbekistan Concludes Site and External Events Design (SEED) Review for the Country's First Nuclear Power Plant", Press Release 8/2023, International Atomic Energy Agency, 27 January 2023, see https://www.iaea.org/newscenter/pressreleases/iaea-team-in-uzbekistan-concludes-site-and-external-events-design-seed-review-for-the-countrys-first-nuclear-power-plant, accessed 25 April 2023.

1306 - World Development Indicators Database, "Gross Domestic Product 2021", World Bank, 1 July 2023, see https://databankfiles.worldbank.org/public/ddpext_download/GDP.pdf, accessed 6 October 2023.

1307 - *NEI Magazine*, "Indonesia signs MOU on molten salt reactor", *Nuclear Engineering International*, 31 July 2020, see https://www.neimagazine.com/news/newsindonesia-signs-mou-on-molten-salt-reactor-8055819/, accessed 1 May 2021.

1308 - Aditya Hadi, "ThorCon submits paperwork for Indonesia's first nuclear power plant", *The Jakarta Post*, as published on *Asia News Network*, 30 March 2023, see https://asianews.network/thorcon-submits-paperwork-for-indonesias-first-nuclear-power-plant/, accessed 17 October 2023.

1309 - Sung-Mi Kim, "Indonesia's Nuclear Dream, Revived?", *The Diplomat*, 31 December 2020, see https://thediplomat.com/2020/12/indonesias-nuclear-dream-revived/, accessed 1 May 2021.

1310 - Marc Roussot, "Southeast Asia Rethinks Nuclear Energy", *Nuclear Intelligence Weekly*, 24 June 2022.

In January 2023, the head of nuclear research at Indonesia's National Research & Innovation Agency (BRIN), Rohadi Awaludin, announced that the National Energy Council (DEN) was preparing to establish a Nuclear Energy Programme Implementation Organisation (NEPIO) reportedly to improve the investment climate for the construction of nuclear power plants.[1311] The idea has been around for years.

Jordan

Since its establishment in 2008,[1312] the Jordan Atomic Energy Commission (JAEC) has gone through a series of unsuccessful options to import a nuclear power plant. These range from importing two 1,000-MW nuclear reactors from Russia,[1313] to importing a High Temperature Reactor from the China National Nuclear Corporation,[1314] to exploring a range of small modular reactor designs including X-energy and NuScale.[1315] The latest addition to that list is a floating nuclear power plant, presumably from Russia, to be located in the Gulf of Aqaba.[1316] However, there are few details and it remains to be seen if JAEC will succeed in this plan at least.

In 2020, the Ministry of Energy and Mineral Resources issued a Jordan Energy Strategy for the period from 2020 to 2030. That strategy envisioned only preparing "feasibility studies" to be carried out before 2030 when it comes to generating "electricity from nuclear energy".[1317] It also stated that the anticipated time frame for deployment is "Post 2030 given the need of the electric power system" and specified that "availability of required funding" was a prerequisite.

To date, Jordan only operates a small (5 MWth) research and training reactor imported from South Korea that does not generate power.[1318] The other nuclear activity that Jordan is involved in is uranium mining and processing, having established the Jordanian Uranium Mining

1311 - *NEI Magazine*, "Indonesia adopts regulation on uranium mining and prepares for possible NPP", 3 January 2023, see https://www.neimagazine.com/news/newsindonesia-adopts-regulation-on-uranium-mining-and-prepares-for-possible-npp-10485065, accessed 3 January 2023.

1312 - JAEC, "About Us", Jordan Atomic Energy Commission, 2021, see http://www.jaec.gov.jo/Pages/viewpage?pageID=1, accessed 1 May 2021.

1313 - Rosatom, "Russia and Jordan signed Project Development Agreement on Nuclear Power Plant Construction", Press Release, 22 September 2014, see https://rosatom-europe.com/press-centre/news/197-russia-and-jordan-signed-project-development-agreement-on-nuclear-power-plant-construction/; and *AP*, "Russia to build Jordan's first nuclear power plant", as published in *Al Jazeera*, 24 March 2015, see https://www.aljazeera.com/news/2015/3/24/russia-to-build-jordans-first-nuclear-power-plant; also Mohammad Ghazal, "Funding issues behind scrapping nuclear deal with Russia", *Jordan Times*, 12 June 2018, see http://www.jordantimes.com/news/local/funding-issues-behind-scrapping-nuclear-deal-russia-%E2%80%94-jaec, all accessed 30 July 2023.

1314 - Mohammad Ghazal, "Jordan, China in 'serious talks' to build gas-cooled $1b reactor", *Jordan Times*, 28 April 2018, see https://www.jordantimes.com/news/local/jordan-china-serious-talks%E2%80%99-build-gas-cooled-1b-reactor, accessed 8 May 2018.

1315 - Phil Chaffee, "Jordan: NuScale a Finalist in SMR Competition", *NIW*, 18 January 2019; and *WNN*, "NuScale SMR to be considered for use in Jordan", *World Nuclear News*, 15 January 2019, see http://www.world-nuclear-news.org/Articles/NuScale-SMR-to-be-considered-for-use-in-Jordan; also *NEI Magazine*, "Jordan and X-energy agree to accelerate work on SMR", *Nuclear Engineering International*, 22 November 2019, see https://www.neimagazine.com/news/newsjordan-and-x-energy-agree-to-accelerate-work-on-smr-7527332; and *WNN*, "Rolls-Royce to conduct SMR study for Jordan", 9 November 2017, see http://www.world-nuclear-news.org/NN-Rolls-Royce-to-conduct-SMR-study-for-Jordan-09111702.html; all accessed 30 July 2023.

1316 - *NEI Magazine*, "Jordan considers floating NPPs", *Nuclear Engineering International*, 28 April 2023, see https://www.neimagazine.com/news/newsjordan-considers-floating-npps-10798331, accessed 29 April 2023.

1317 - MEMR, "The Executive Action Plan of Jordan Energy Strategy: 2020-2030", Ministry of Energy and Mineral Resources, Government of Jordan, 2020, see https://www.memr.gov.jo/EBV4.0/Root_Storage/EN/EB_Info_Page/ActionPlanEN2020.pdf, accessed 25 August 2023.

1318 - *WNN*, "Jordan research reactor complete", *World Nuclear News*, 12 December 2016, see https://www.world-nuclear-news.org/Articles/Jordan-research-reactor-complete, accessed 4 May 2021.

Company (JUMCO) in 2013.[1319] It has been operating a pilot scale uranium processing plant since 2021.[1320] In 2022, the company announced that it had processed 160 tons of uranium ore to produce symbolic 20 kg of yellowcake.[1321] The long-term goal, according to JAEC Chairman Khaled Toukan, is to produce 400-800 tons of yellowcake per year.[1322]

Meanwhile, Jordan's renewable energy capacity has been growing quite rapidly, from 17 MW in 2013 to 2.6 GW in 2022, with an 18-percent increase in just the last year.[1323] Most of this consists of solar energy installations, with a total capacity of 1.9 GW as of 2022, an increase of 26 percent compared to previous year; till 2014, there was no solar PV capacity in the country.

Thailand

In June 2007, the Thai Cabinet set up the Nuclear Power Program Development Office under the National Energy Policy Council and appointed an Infrastructure Establishment Committee, of which the Nuclear Power Utility subcommittee is supervising the electricity utility (Electricity Generating Authority of Thailand or EGAT) in assessing the options for nuclear power. Since then, various policy options and companies have been considered, and in December 2015, Thailand's Ratchaburi Electricity Generating Holding Public Co. decided to buy a 10-percent stake in a newbuild project in China, the twin Hualong One units Fangchenggang-3 and -4.[1324] The first unit was connected to the grid in January 2023.

In April 2017, China and Thailand signed a nuclear co-operation agreement. At that occasion, China General Nuclear Power Group (CGN) stated that "China is very willing to provide Thailand with the most advanced, most economical and safest nuclear power technology, as well as equipment, management experience and quality service."[1325] However, since then, CGN has been blacklisted by the U.S. and there seems to have been no progress in developing nuclear power in Thailand.

In November 2022, the U.S. entered the scene with a high-level visit of Vice-President Kamala Harris launching the Foundational Infrastructure for Responsible Use of Small Modular Reactor Technology (FIRST) Program. In a factsheet, the U.S. Administration states that the new partnership "builds on almost 50 years of U.S.-Thailand civil nuclear cooperation". However, those five decades have not led to an operating nuclear power reactor. The FIRST

1319 - JAEC, "Jordan Nuclear Program—Jordanian Uranium Project", Jordan Atomic Energy Commission, 2022, see https://jaec.gov.jo/Pages/viewpage?pageID=31, accessed 25 July 2022.

1320 - *The Jordan Times*, "Jordanian Uranium Mining Company's yellowcake plant fully operational — Toukan", 24 July 2021, see https://www.jordantimes.com/news/local/jordanian-uranium-mining-companys-yellowcake-plant-fully-operational-%E2%80%94-toukan, accessed 22 July 2022.

1321 - Raed Omari, "Jordan announces uranium production", *Arab News*, 14 May 2022, see https://www.arabnews.com/node/2082031/middle-east, accessed 10 August 2022; and *WNN*, "Jordan announces uranium production", *World Nuclear News*, 13 May 2022, see https://www.world-nuclear-news.org/Articles/Jordan-announces-uranium-production, accessed 14 May 2022.

1322 - *Jordan News*, "JAEC seeks to produce 800 tonnes of yellowcake annually", 18 March 2023, see https://www.jordannews.jo/Section-109/News/JAEC-seeks-to-produce-800-tonnes-of-yellowcake-annually-27601, accessed 29 June 2023.

1323 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

1324 - *Nuclear Intelligence Weekly*, "Potential and Existing Conventional Nuclear Newbuild Projects (Generation III or Earlier) Currently Planned", 24 September 2021.

1325 - *WNN*, "China, Thailand agree to nuclear energy cooperation", *World Nuclear News*, 5 April 2017, see https://www.world-nuclear-news.org/NP-China-Thailand-agree-to-nuclear-energy-cooperation-0504174.html, accessed 1 May 2021.

program is meant "to explore options to advance Thailand's goal of Net Zero Emissions by 2065 through deployment of small modular reactors (SMRs)".[1326]

Vietnam

Vietnam, with its growing economy and energy demand, for decades had been seen as a model candidate to develop nuclear power, and in October 2010, Vietnam signed an intergovernmental agreement with Russia's Atomstroyexport to build the Ninh Thuan-1 nuclear power plant, using VVER-1200 reactors. Construction was expected to begin in 2014, with the turnkey project being owned and operated by the state utility Vietnam Electricity (EVN). A second agreement was also signed with Japanese companies to develop an additional plant.[1327] However, ambitions were severely curtailed in November 2016, when 92 percent of the voting members of the National Assembly approved a government motion to cancel the proposed nuclear projects with both Russia and Japan, due to slowing electricity demand increases, concerns about safety, rising construction costs, and the financial burden of billions of dollars in loans.[1328]

Despite this, a draft power plan published by the Ministry of Industry and Trade in July 2020 envisaged building nuclear power plants with a capacity of 5 GW by 2045.[1329] In May 2022, Nguyen Hong Dien, Minister of Industry and Trade, told the National Assembly developing nuclear power would be "an inevitable trend". The Minister added that the Russian and Japanese projects had been "suspended" in 2016, not "canceled", implying that authorities could revive the project.[1330]

In the meantime, renewable capacity deployment in Vietnam represents 40 percent of the expected increase over the period 2021–2026 in all ASEAN member countries.[1331] In 2020 alone, a total of 9.3 GW of rooftop solar was installed. The country already has over 100,000 rooftop solar installations.

The final version of the Power Development Plan (PDP8), published in May 2023, does not refer to nuclear power. It proposes to raise total power generating capacity from 69 GW in 2020 to 150 GW by 2030. This would see relative shares of natural gas with close to 25 percent, coal 20 percent, wind 18.5 percent and utility scale solar (excl. rooftop) 8.5 percent. According to the plan, non-hydro renewables will represent a minimum of 31 percent in 2030 plus 19.5 percent hydro.[1332] In addition, the plan stipulates that half of office buildings and half residential buildings "use self-consumption solar power models (power is consumed in the area where it

1326 - The White House, "Fact Sheet: Vice President Harris Announces New Initiatives to Strengthen U.S.-Thailand Alliance and to Support Mekong Sub-Region", Press Release, U.S. Government, 18 November 2022, see https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/18/fact-sheet-vice-president-harris-announces-new-initiatives-to-strengthen-u-s-thailand-alliance-and-to-support-mekong-sub-region/, accessed 7 October 2023.

1327 - *WNN*, "Vietnam prepares for nuclear power", 6 October 2011, see https://www.world-nuclear-news.org/Articles/Vietnam-prepares-for-nuclear-power, accessed 1 May 2021.

1328 - *NIW*, "Briefs – Vietnam", *Nuclear Intelligence Weekly*, 28 November 2016.

1329 - Anh Minh, "Vietnam mulls return to nuclear energy after 2035", *VnExpress International*, 9 July 2020, see https://e.vnexpress.net/news/business/economy/vietnam-mulls-return-to-nuclear-energy-after-2035-4127854.html, accessed 1 May 2021.

1330 - Myriam Boulianne, "Southeast Asia tempted by nuclear power", *Le Monde*, 25 June 2022, see https://www.lemonde.fr/en/economy/article/2022/06/25/southeast-asia-tempted-by-nuclear-power_5987975_19.html, accessed 24 August 2022.

1331 - IEA, "Renewables 2021", revised version, December 2021.

1332 - Khanh Vu and Francesco Guarascio, "Vietnam approves plan to boost wind, LNG by 2030", *Reuters*, 16 May 2023, see https://www.reuters.com/business/energy/vietnams-pm-approves-135-billion-power-plan-2030-2023-05-15/, accessed 8 October 2023.

is generated instead of being sold to national electricity system)" and "self-consumption solar power sources are prioritized for unlimited development".[1333]

In July 2023, *VNExpress International* reported under the headline "Central province returns lands as nuclear power plants aborted" that Ninh Thuan Province is set to return land it had acquired from 1,000 families for the construction of two nuclear power plants. The provincial announcement to this effect reportedly stated, "the Ninh Thuan 1 and 2 plants, proposed to be built in Thuan Nam and Ninh Hai districts, have been called off."[1334]

1333 - Prime Minister of Vietnam, "Decision 500/QD-TTg 2023 National Electricity Development Planning of 2021 - 2030 in Vietnam", 15 May 2023, see https://thuvienphapluat.vn/van-ban/EN/Thuong-mai/Decision-500-QD-TTg-2023-National-Electricity-Development-Planning-of-2021-2030/566836/tieng-anh.aspx, accessed 8 October 2023.

1334 - Viet Quoc, "Central province returns lands as nuclear power plants aborted", *VnExpress International*, 13 July 2023, see https://e.vnexpress.net/news/news/central-province-returns-lands-as-nuclear-power-plants-aborted-4629079.html, accessed 8 October 2023.

SMALL MODULAR REACTORS (SMRs)

Although virtually no small modular reactors (SMRs) have been built, the topic of SMRs continue to hog media headlines. Reports from international organizations like the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) list dozens of SMR designs, said to be developed by private and public companies. The 2022-edition of IAEA's "Advances in Small Modular Reactor Technology Developments", for example, includes 83 designs.[1335] Quite a few of these designs have been abandoned: the case of mPower was discussed at some length in WNISR2017.[1336] More generally, there is a significant gap between the reality on the ground and what such agencies, and the general media, report about SMRs. For example, in 2023 the NEA released what it termed a SMR Dashboard, and this claimed to reveal "substantial progress towards SMR deployment and commercialization in NEA and non-NEA member countries, with much of this progress taking place during the past two years".[1337] But as documented in WNISR2021 and WNISR2022, the only SMRs deployed during the past two years are the twin-High Temperature Gas Cooled Reactor units in China (the twin KLT-40S units in Russia started operating in 2020).

Despite such hype and the flurry of Memoranda of Understanding (MoU) and other such non-binding agreements, these SMRs are the only two that are operating—and reportedly not too well. The experience so far in constructing these two SMRs as well as estimates for reactor designs like NuScale's SMR show that these designs are also subject to the historical pattern of cost escalations and time overruns. Those cost escalations do make it even less likely that SMRs will become commercialized, as the collapse of the Carbon Free Power Project involving NuScale reactors in the United States illustrated.

The delays delays are of particular concern because governments are including deployment of SMRs in their climate mitigation plans. As the climate crisis mounts in intensity, international organizations like the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Secretariat call for very rapid reductions in carbon emissions. SMRs, and new nuclear power in general, are out of line with this requirement.

1335 - IAEA, "Advances in small modular reactor technology developments—A Supplement to: IAEA Advanced Reactors Information System (ARIS)—2022 Edition", International Atomic Energy Agency, September 2022, see https://aris.iaea.org/Publications/SMR_booklet_2022.pdf, accessed 6 November 2023.

1336 - Mycle Schneider, Antony Froggatt et al., "The World Nuclear Industry Status Report 2017", Mycle Schneider Consulting, September 2017, see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2017-HTML.html#link85, accessed 6 November 2023.

1337 - OECD/NEA, "The NEA Small Modular Reactor Dashboard", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, March 2023, see https://www.oecd-nea.org/upload/docs/application/pdf/2023-02/7650_smr_dashboard.pdf, accessed 13 March 2023.

ARGENTINA

Argentina's National Atomic Energy Commission (CNEA) has been developing the CAREM (Central Argentina de Elementos Modulares) design since the 1980s.[1338] Construction of the 25-MW reactor started in February 2014, when the CNEA projected that the reactor was "scheduled to begin cold testing in 2016 and receive its first fuel load in the second half of 2017".[1339] In October 2022, when IAEA Director General Rafael Grossi toured Argentinian nuclear facilities, the CNEA President announced the "hope" that the reactor would become critical "by the end of 2027".[1340] Assuming that the hope is realized, the reactor would be delayed by a decade. (See section on Argentina in Annex 1)

CANADA

Canadian government entities have been promoting small modular reactors for many years, especially after the publication of the 2018 SMR roadmap, which offered many recommendations to help "capitalize on Canada's SMR opportunity", important of which were funding for demonstration projects and policy changes at multiple levels.[1341] In February 2023, the Parliament's Standing Committee on Science and Research issued a report on SMRs whose first recommendation was that the government continue to support SMR projects by sharing their development-phase costs.[1342] However, the report followed this with recommendations for a more cautious approach, including to undertake transparent and independent scientific reviews and to work with international and scientific peers to examine spent fuel reprocessing, which is a part of some SMR proposals, and its implications for waste management and proliferation vulnerability. The federal government's response to the report acknowledged that nuclear reprocessing is "a sensitive technology" and committed to "ensure that such technologies would not negatively affect nuclear non-proliferation priorities of Canada and its allies."[1343]

As detailed in previous WNISR editions, the government has been offering considerable funding for SMRs and that trend has been continuing. This includes tens of millions of dollars to SMR

1338 - Dario F. Delmastro, "Small modular reactors (SMRs): The case of Argentina", National Atomic Energy Commission and Universidad Nacional de Cuyo, in "Handbook of Small Modular Nuclear Reactors", ed. by Daniel T. Ingersoll and Mario D. Carelli, *Woodhead Publishing*, November 2020, see https://www.sciencedirect.com/science/article/pii/B978012823916200014X, accessed 7 August 2023; and U.S. House of Representatives, "Oversight review of South American science, space, and technology: report to the Committee on Science, Space, and Technology, U.S. House of Representatives, One Hundredth Congress, second session", U.S. Government Printing Office, 1988.

1339 - *WNN*, "Construction of CAREM underway", *World Nuclear News*, 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2021.

1340 - *AgendAR*, "Grossi: 'El Carem es un proyecto muy importante en el desarrollo de la energía nuclear", 20 October 2022 (in Spanish), see https://agendarweb.com.ar/2022/10/20/grossi-el-carem-es-un-proyecto-muy-importante-en-el-desarrollo-de-la-energia-nuclear/, accessed 15 July 2023.

1341 - Canadian Small Modular Reactor Roadmap Steering Committee, "A Call to Action: A Canadian Roadmap for Small Modular Reactors", November 2018, see https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf, accessed 14 June 2019.

1342 - Standing Committee on Science and Research, "Small modular nuclear reactors", House of Commons, Canada, 44th Parliament, 1st Session, February 2023, see https://www.ourcommons.ca/Content/Committee/441/SRSR/Reports/RP12212540/srsrrp03/srsrrp03-e.pdf, accessed 28 July 2023.

1343 - Minister of Natural Resources, "Government Response to the Third Report of the Standing Committee on Science and Research", Government of Canada, addressed to the Standing Committee on Science and Research, House of Commons, 9 June 2023, see https://www.ourcommons.ca/DocumentViewer/en/44-1/SRSR/report-3/response-8512-441-199, accessed 3 August 2023.

vendors, and smaller amounts to researchers at universities and other institutions. The biggest funding package came in the form of a commitment for CAD970 million (US$708 million) from the Federal Infrastructure Bank to Ontario Power Generation to build an SMR at the Darlington site.[1344] In February 2023, the government announced another funding program ("The Enabling Small Modular Reactors Program") that would offer CAD29.6 million (US$22.2 million) over four years to projects aiming to develop supply chains for SMR manufacture and fuel supply, and research management strategies for nuclear wastes SMRs would produce.[1345] A month later, the federal budget included new tax breaks for "manufacturing of nuclear energy equipment" and "processing or recycling of nuclear fuels".[1346] The latter seems to be a reference to the ongoing Moltex SMR spent fuel reprocessing research funded by the federal and provincial governments and conducted by SNC Lavalin.

The Canadian Nuclear Safety Commission (CNSC) has continued to offer an optional service for SMR companies called "pre-licensing vendor design review" that is meant to enable CNSC staff "to provide feedback early in the design process" but "does not certify a reactor design or involve the issuance of a licence under the Nuclear Safety and Control Act, and it is not required as part of the licensing process for a new nuclear power plant. The conclusions of any design review do not bind or otherwise influence decisions made by the Commission".[1347] In January 2023, CNSC started reviewing Westinghouse's eVinci design.[1348] However, it was late June by the time Westinghouse submitted its first set of Vendor Design Review documents to CNSC.[1349]

The most likely contender for the first SMR to be built in Canada is the 15 MW (thermal) Micro Modular Reactor Project which would "generate electrical power and/or heat over an operating lifespan of 20 years" and is implemented by a company called Global First Power along with Ultra Safe Nuclear Corporation and Ontario Power Generation (OPG) at the Chalk River Laboratories (CRL) site in Renfrew County, Ontario, about 200 kilometers northwest of Ottawa.[1350] The project requires both an environmental assessment and a licensing assessment; the former, already underway since 15 July 2019, has to be completed before the CNSC can make a licensing decision. Global First Power was expected to submit an environmental impact statement in summer 2023.[1351] But on 28 July 2023, CNSC emailed civil society groups that had

1344 - Matthew Mcclearn, "Federal Infrastructure Bank commits $970-million for small nuclear reactor", *The Globe and Mail*, 26 October 2022.

1345 - Natural Resources Canada, "Canada Launches New Small Modular Reactor Funding Program", Government of Canada, 23 February 2023, see https://www.canada.ca/en/natural-resources-canada/news/2023/02/canada-launches-new-small-modular-reactor-funding-program.html, accessed 28 July 2023.

1346 - Department of Finance, "Federal Budget—Budget 2023—Chapter 3: A Made-In-Canada Plan: Affordable Energy, Good Jobs, and a Growing Clean Economy", Government of Canada, 28 March 2023, see https://www.budget.canada.ca/2023/report-rapport/chap3-en.html, accessed 3 August 2023.

1347 - CNSC, "Pre-Licensing Vendor Design Review", Canadian Nuclear Safety Commission, Updated 20 April 2023, see https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm, accessed 7 August 2023.

1348 - Ibidem

1349 - Westinghouse, "Westinghouse Begins Vendor Design Review for eVinciTM Microreactor with Canadian Nuclear Safety Commission", Press Release, 5 July 2023, see https://info.westinghousenuclear.com/news/westinghouse-begins-vendor-design-review-for-evinci-microreactor-with-canadian-nuclear-safety-commission, accessed 7 August 2023.

1350 - CNSC, "Proposed nuclear facility – Global First Power Micro Modular Reactor Project", Updated 15 May 2023, Canadian Nuclear Safety Commission, Updated 15 May 2023, see https://www.cnsc-ccsn.gc.ca/eng/reactors/research-reactors/nuclear-facilities/chalk-river/global-first-micro-modular-reactor-project.cfm, accessed 20 June 2023.

1351 - Ibidem.

received funding from the CNSC to review the submission that it will be delayed, and Global First Power is now anticipating submitting their statement only in early 2024.

Meanwhile, OPG plans to build up to four of GE-Hitachi's (GEH) BWRX-300 units with 300 MW each at the Darlington site. In October 2022, OPG submitted an application for a license to construct a single unit.[1352] Back in October 2021, CNSC renewed OPG's "nuclear power reactor site preparation licence" that is valid until October 2031.[1353] OPG is arguing that the BWRX-300 project can proceed because the CNSC had issued an environmental assessment in 2009 to construct four large reactors, but civil society groups have objected to doing so because this procedure would not "adequately address the significant changes in [their] understanding of the likelihood, types, and consequences of nuclear accidents which have occurred since [the] 2009 licence application".[1354]

As mentioned, in October 2022, the government's Canada Infrastructure Bank announced that it will provide a low-interest loan of CAD970 million (US$708 million) towards this project.[1355] In March 2023, the CNSC released the executive summary of the pre-licensing vendor design review of the BWRX-300 design stating that while CNSC staff "did not identify any fundamental barriers to licensing… the review did reveal some technical areas that need further development in order for GEH to better demonstrate adherence to CNSC requirements (…)".[1356]

The other province that has been at the center of SMR activity in Canada is New Brunswick. On 30 June 2023, the province's electricity company, NB Power, applied to the CNSC for a license to start preparing the Point Lepreau site as part of its plans to construct and operate the ARC-100 sodium cooled fast reactor by the early 2030s.[1357] The ARC-100 has so far only completed Phase 1 of CNSC's Pre-licensing Vendor Design Review.[1358] Notably, all designs currently considered for construction are not of Canadian origin.

1352 - CNSC, "Darlington New Nuclear Project", Canadian Nuclear Safety Commission, 11 January 2023, see http://www.nuclearsafety.gc.ca/eng/resources/status-of-new-nuclear-projects/darlington/index.cfm, accessed 11 January 2023.

1353 - CNSC, "CNSC renews Ontario Power Generation's site preparation licence for its Darlington New Nuclear Project", Press Release, Canadian Nuclear Safety Commission, 12 October 2021, see https://www.canada.ca/en/nuclear-safety-commission/news/2021/10/cnsc-renews-ontario-power-generations-site-preparation-licence-for-its-darlington-new-nuclear-project.html, accessed 5 September 2023.

1354 - Sara Libman, "Review of OPG's Updated Plant Parameter Envelope and Environmental Impact Statement Review reports for the Darlington New Nuclear Project", Canadian Environmental Law Association, 23 March 2023, see https://cela.ca/review-of-opgs-updated-plant-parameter-envelope-and-environmental-impact-statement-review-reports-for-the-darlington-new-nuclear-project/, accessed 2 August 2023.

1355 - Matthew Mcclearn, "Federal Infrastructure Bank commits $970-million for small nuclear reactor", *The Globe and Mail*, 26 October 2022; and OPG, "CIB commits $970 million towards Canada's first Small Modular Reactor", Press Release, Ontario Power Generation, 25 October 2022, see https://www.opg.com/media_releases/cib-commits-970-million-towards-canadas-first-small-modular-reactor/, accessed 7 August 2023.

1356 - CNSC, "Executive summary: Combined phases 1 and 2 pre-licensing vendor design review – General Electric Hitachi Nuclear Energy", Candian Nuclear Safety Commission, Updated 15 March 2023, see https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/geh-nuclear-energy-executive-summary.cfm, accessed 7 August 2023.

1357 - NB Power, "NB Power Submits Environmental Impact Assessment Registration and Licence to Prepare Site Application for Advanced Small Modular Reactor Project", Press Release, 30 June 2023, see http://www.nbpower.com/en/about-us/news-media-centre/news/2023/nb-power-submits-environmental-impact-assessment-registration-and-licence-to-prepare-site-application-for-advanced-small-modular-reactor-project/; and NB Power, "License to Prepare Site Application— 930-00581-0001-001-LPA-A-00", 30 June 2023, see https://www.nbpower.com/media/1492441/licensetopreparesiteapplication.pdf, accessed 7 August 2023.

1358 - CNSC, "Pre-Licensing Vendor Design Review", Updated 18 April 2023, Canadian Nuclear Safety Commission, 18 April 2023, see https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm, accessed 19 April 2023.

Canada Energy Regulator's 2023 "Canada's Energy Future" report developed scenarios for a path to net zero by 2050, all of which project roughly a tripling of nuclear energy generation capacity in Canada by 2050, almost completely based on SMRs.[1359] These scenarios, however, were based on unrealistic assumptions about the costs of SMRs that were far below the costs of SMR designs like Argentina's CAREM and the U.S. NuScale.[1360]

But grid planners seem to envision far more modest growth. The 2022 Annual Planning Outlook from Ontario's Independent Electricity System Operator that maps out the 2024–2043 time frame includes only one 300-MW SMR in its list of "resources that are expected to come online over the study horizon".[1361] New Brunswick's NB Power's Integrated Resource Plan (IRP) assumed two first of a kind SMRs by 2035 with a total capacity of 450 to 750 MW in different scenarios, but the document noted explicitly in a footnote that the "IRP does not include any cost estimates for SMRs and they are therefore not treated as an economic supply option in the expansion plan optimization".[1362]

CHINA

Although there are multiple SMR designs proposed by the nuclear industry and researchers in China, only two SMR designs are currently under construction. The earlier design is a high temperature gas cooled reactor (HTGR) called the HTR-PM and the latter design is an integral pressurized water reactor named ACP100. An earlier plan to build floating nuclear reactors appears to have been suspended.[1363] China has been exploring the possibility of exporting SMRs, especially the HTGR design, and signed a Memorandum of Understanding with Saudi Arabia on the construction of a high-temperature gas-cooled reactor in 2016,[1364] followed by the launch of a feasibility study the following year.[1365] But more recent news reports suggest that

1359 - Canada Energy Regulator, "Canada's Energy Future 2023—Energy Supply and Demand Projections to 2050", Updated 3 March 2021, see https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2023/canada-energy-futures-2023.pdf, accessed 11 August 2023.

1360 - M. V. Ramana and Susan O'Donnell, "Wishful thinking about nuclear energy won't get us to net zero", *The Hill Times*, 3 July 2023, see https://www.hilltimes.com/story/2023/07/03/wishful-thinking-about-nuclear-energy-wont-get-us-to-net-zero/391721/, accessed 5 September 2023.

1361 - IESO, "Annual Planning Outlook - Ontario's electricity system needs: 2024-2043", Independent Electricity System Operator, December 2022, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Dec2022/2022-Annual-Planning-Outlook.ashx, accessed 4 April 2023.

1362 - NB Power, "2023 Integrated Resource Plan—Pathways to a Net-Zero Electricity System", New Brunswick Power Corporation, July 2023, see https://www.nbpower.com/media/1492536/2023_irp.pdf, accessed 6 November 2023.

1363 - Stephen Chen, "China suspends plan to build floating nuclear reactors in the South China Sea", *South China Morning Post*, 31 May 2023, see https://www.scmp.com/news/china/science/article/3222289/china-suspends-plan-build-floating-nuclear-reactors-south-china-sea, accessed 15 July 2023.

1364 - *WNN*, "China, Saudi Arabia agree to build HTR", 20 January 2016, see https://world-nuclear-news.org/Articles/China,-Saudi-Arabia-agree-to-build-HTR, accessed 2 June 2021.

1365 - *NEI Magazine*, "China and Saudi Arabia accelerate co-operation on HTGRs", 18 May 2017, see https://www.neimagazine.com/news/newschina-and-saudi-arabia-accelerate-co-operation-on-htgrs-5818189, accessed 6 November 2023.

China is interested in building (large) Hualong One design reactors in Saudi Arabia.[1366] China has also explored building the HTGR design in Jordan,[1367] but this plan too has not progressed.

HTR-PM Design

The HTR-PM, which consists of two 100 MW reactors connected to a single turbine, builds on the experience with the pilot scale HTR-10 reactor, which in turn can be traced back to the 80 MW HTR-MODUL design developed by a joint venture of Siemens and Asea Brown Boveri (ABB) in the late 1980s.[1368] The HTR-PM project was designed by Tsinghua University and was launched in 2001, soon after the HTR-10 attained criticality.

The first pour of concrete for the HTR-PM was scheduled for “spring 2007” and the plant was projected to start operating “by the end of the decade”.[1369] In other words, the expectation was that it would take less than three years to move from initiation of construction to operations. But construction started only in December 2012, and by then the time estimate had increased to “50 months”.[1370] In the end, the project reached first criticality only in 2021, and the two 100 MW reactors reached full power in December 2022.[1371] Thus, the HTR-PM took ten years to go from first pour of concrete to reaching full power.

Even after that, it appears that the HTR-PM is not operating properly. Between January and December 2022, the reactors operated for only 27 hours out of a possible maximum of 8,760 hours.[1372] In the subsequent three months, they seem to have operated at a load factor of around 10 percent.[1373]

1366 - Dan Yurman, “Saudi Arabia Says It Might Select China for Nuclear Reactors”, *Neutron Bytes*, 26 August 2023, see https://neutronbytes.com/2023/08/26/saudi-arabia-says-it-might-select-china-for-nuclear-reactors/, accessed 10 September 2023.

1367 - Joy Nasr and Ali Ahmad, “Middle East Nuclear Energy Monitor: Country Perspectives 2018”, Energy Policy and Security Program, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, January 2019; and Ali Ahmad and M. V. Ramana, “HTRs will not help establish nuclear power in Jordan”, *The Jordan Times*, 10 May 2018, see http://www.jordantimes.com/opinion/ali-ahmad-and-m-v-ramana/htrs-will-not-help-establish-nuclear-power-jordan, accessed 18 May 2018.

1368 - M.V. Ramana, Laura Berzak Hopkins and Alexander Glaser, “Licensing small modular reactors”, Nuclear Futures Laboratory and Program on Science and Global Security, Princeton University, *Energy,* Vol. 61, November 2013, see http://www.sciencedirect.com/science/article/pii/S0360544213007615, accessed 7 November 2013.

1369 - Spencer Reiss, “Let a Thousand Reactors Bloom”, *Wired, 1 September 2004, see* https://www.wired.com/2004/09/china-5/, accessed 16 July 2022; and Zuoyi Zhang, Zongxin Wu et al., “Design of Chinese Modular High-Temperature Gas-Cooled Reactor HTR-PM”, in 2nd International Topical Meeting on High Temperature Reactor Technology, 22 September 2004.

1370 - David Dalton, “China Begins Construction Of First Generation IV HTR-PM Unit”, *NucNet*, 7 January 2013, see http://www.nucnet.org/all-the-news/2013/01/07/china-begins-construction-of-first-generation-iv-htr-pm-unit, accessed 10 January 2013.

1371 - *NEI Magazine*, “Grid connection for unit 1 of China’s HTR-PM project”, 21 December 2021, see https://www.neimagazine.com/news/newsgrid-connection-for-unit-1-of-chinas-htr-pm-project-9337084; and *WNN*, “China’s demonstration HTR-PM reaches full power”, 9 December 2022, see https://www.world-nuclear-news.org/Articles/China-s-demonstration-HTR-PM-reaches-full-power; both accessed 20 December 2022.

1372 - Department of Nuclear Power Evaluation, “全国核电运行情况（2022年1-12月）”, China Nuclear Energy Association, 2 February 2023 (in Chinese), see https://www.china-nea.cn/site/content/42324.html, accessed 8 August 2023.

1373 - Department of Nuclear Power Evaluation, “全国核电运行情况（2023年1-3月）”, China Nuclear Energy Association, 9 May 2023 (in Chinese), see https://www.china-nea.cn/site/content/42751.html, accessed 8 August 2023.

ACP100 Design

The ACP100 integrated PWR, also referred as Linglong One, has been in the developmental phase since 2010, and its initial design was finalized in 2014.[1374] Construction of the 100-MW Linglong One started in July 2021 at the Changjiang site in Hainan province, which is already home to two operating CNP600 PWRs, and two Hualong One units under construction.[1375] As detailed in WNISR2022, this start date is at least six years behind schedule. In September 2023, CNNC projected that the reactor would be put into operation by 2026.[1376]

FRANCE

France's fourth attempt at an SMR design started in earnest in February 2022 when President Emmanuel Macron announced that "€1 billion [US$$_{2022}$1.1 billion] will be made available through the France 2030 re-industrialization plan" for the Nuward SMR and for "innovative reactors to close the fuel cycle and produce less waste", and that "he had set 'an ambitious goal' to construct a first prototype in France by 2030".[1377] According to EDF, €0.5 billion of this amount is earmarked for Nuward development.[1378] As described in WNISR2022, the three earlier SMR designs that France pursued were the Flexblue, Antares, and NP-300, all of which appear to have been discontinued.

The Nuward project itself is not new, having been first revealed in September 2019.[1379] Since then, in March 2023, EDF has set up a new subsidiary company, Nuward, that will carry out "the basic design" of the reactor.[1380] According to EDF, as of mid-2023, the French government

1374 - *WNN*, "Rapid construction of Chinese SMR containment shell continues", *World Nuclear News*, 7 July 2022, see https://www.world-nuclear-news.org/Articles/Rapid-construction-of-Chinese-SMR-containment-shel, accessed 17 July 2022; and Bin Xu, "CNNC's ACP100 SMR: Technique Features and Progress in China", China National Nuclear Corporation, Nuclear Power Institute of China, presented at "13th INPRO Dialogue Forum on Legal and Institutional Issues in the Global Deployment of Small Modular Reactors", IAEA, 18–21 October 2016, see https://nucleus.iaea.org/sites/INPRO/df13/Presentations/011_CNNC%27s%20ACP100%20SMR-Technique%20Features%20and%20Progress%20in%20China.pdf, accessed 8 August 2023.

1375 - CNNC, "World's first commercial Linglong One onshore small reactor starts construction", Press Release, China National Nuclear Corporation, 14 July 2021, see https://en.cnnc.com.cn/2021-07/14/c_642603.htm; and WNA, "Changjiang SMR-1, China", Undated, World Nuclear Association, see https://www.world-nuclear.org/reactor/default.aspx/CHANGJIANG%20SMR; also *NS Energy*, "Hainan Changjiang Nuclear Power Plant Phase Two", Undated, see https://www.nsenergybusiness.com/projects/hainan-changjiang-nuclear-power-plant/; all accessed 8 August 2023.

1376 - CNNC, "Workshop on the Application of Small Modular Reactor held in Hainan", China National Nuclear Corporation, 8 September 2023, see https://en.cnnc.com.cn/2023-09/08/c_919054.htm, accessed 8 November 2023.

1377 - *WNN*, "Macron sets out plan for French nuclear renaissance", 11 February 2022, see , accessed 19 February 2022; and President Emmanuel Macron, "Déclaration de M. Emmanuel Macron, président de la République, sur la politique de l'énergie, à Belfort le 10 février 2022.", French President, 10 February 2022, see https://www.vie-publique.fr/discours/283773-emmanuel-macron-10022022-politique-de-lenergie, accessed 8 August 2023.

1378 - EDF, "EDF group Half-Year Financial Report at 30 June 2023", Electricité de France, July 2023, see https://www.edf.fr/sites/groupe/files/2023-07/2023-07-27-half-year-results-financial-report.pdf, accessed 10 September 2023.

1379 - *WNN*, "French-developed SMR design unveiled", 17 September 2019, see https://www.world-nuclear-news.org/Articles/French-developed-SMR-design-unveiled, accessed 22 July 2022; and CEA, "CEA, EDF, Naval Group and TechnicAtome unveil NUWARD: jointly developed Small Modular Reactor (SMR) project", Press Release, Commissariat à l'énergie atomique et aux énergies alternatives/French Alternative Energies and Atomic Energy Commission, 17 October 2019, see https://www.cea.fr/english/Pages/News/Nuward-SMR-CEA.aspx, accessed 8 August 2023.

1380 - EDF, "EDF announces the creation of its subsidiary NUWARD to boost the development of its SMR now entering the basic design phase", Press Release, 30 March 2023, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-announces-the-creation-of-its-subsidiary-nuward-to-boost-the-development-of-its-smr-now-entering-the-basic-design-phase, accessed 8 August 2023.

had provided €350 million (US$384 million) in funding for Nuward development, and this was the "first tranche of the €500 million" announced by the French President in February 2022.[1381]

The basic concept is a two-unit plant with two 170-MW PWR modules. And according to EDF, these are "designed to be built in large numbers and widely exportable. Its main target is as a replacement for fossil-fired plants in the next few decades. Sales will be backed up by a model plant in France that is due to start construction by 2030".[1382] The timeline presented by Nuward's CEO in May 2023 sees the just-started Basic Design studies completed by 2026, Detailed Design ready by 2029, with construction starting the following year.[1383] Going by the experience with other SMR designs, this schedule is ambitious, to say the least.

EDF has been signing agreements with other European countries—with Fortum to explore building Nuward in Sweden and Finland (December 2022),[1384] and with Poland's Respect Energy (January 2023).[1385] In June 2022, safety regulators from France, Czech Republic, and Finland announced an initiative to jointly assess "the main safety options envisaged by EDF, notably the target safety objectives, the safety approach used in the design, the use of passive systems and the integration of two reactor modules within a single facility".[1386] On 19 July 2023, Nuward submitted the "Safety Options File" to the French Nuclear Safety Authority (ASN) marking the "start of the pre-licensing process".[1387]

INDIA

Since the 1990s, India's Department of Atomic Energy (DAE) has been engaged in the development of the Advanced Heavy Water Reactor (AHWR) design, originally aiming for operational status by 2011. However, as described in WNISR2022, there is no indication that construction is due to start anytime soon. There have been no announcements in the past year about this project.

Over the past year, however, Indian government leaders and other organizations, most prominently NITI Aayog, the government's policy think-tank, have been pushing for reorganizing the sector around small modular reactors and involving the private sector.[1388]

1381 - EDF, "EDF group Half-Year Financial Report at 30 June 2023", July 2023, op. cit. p.33.

1382 - Ibidem.

1383 - NUWARD, "NUWARD SMR – Leading the way to a low-carbon world", Audition at the Chamber of Representatives of Belgium, Committee for Energy, Environment and Climate, 30 May 2023, see https://www.lachambre.be/FLWB/PDF/55/3460/55K3460001.pdf, accessed 9 August 2023.

1384 - Phil Chaffee, "EDF's Nuward SMR Plays Catch Up", *Nuclear Intelligence Weekly*, 9 December 2022; and EDF, "EDF and Fortum sign a Framework Cooperation Agreement for Nuclear New Build in Finland and Sweden", Press Release, 8 December 2022, see https://www.edf.fr/sites/groupe/files/epresspack/4381/PR_EDF-and-Fortum-sign-a-Framework-Cooperation-Agreement-for-Nuclear-New-Build-VDEF.pdf, accessed 8 August 2023.

1385 - *NEI Magazine*, "EDF promotes Nuward SMR in Poland", *Nuclear Engineering International*, 19 January 2023, see https://www.neimagazine.com/news/newsedf-promotes-nuward-smr-in-poland-10530031, accessed 22 January 2023.

1386 - EDF, "EDF announces that its Small Modular Reactor NUWARDTM will be the case study for a European early joint regulatory review led by the French nuclear Safety Authority with the participation of the Czech and Finnish safety authorities.", Press Release, 2 June 2022, see https://www.edf.fr/sites/groupe/files/epresspack/3119/PR_EDF1.pdf, accessed 19 June 2023.

1387 - NUWARD, "NUWARD announces the submission of the NUWARD SMR Safety Options File to the French Safety Authority (ASN), which marks the start of the pre- licensing process", Press Release, 21 July 2023, see https://www.nuward.com/sites/nuward/files/2023-07/230721-NUWARD-SMR-DOS-Submission-EN.pdf, accessed 9 August 2023.

1388 - *NEI Magazine*, "India looks to SMRs", 29 November 2022, *Nuclear Engineering International*, see https://www.neimagazine.com/news/newsindia-looks-to-smrs-10393898, accessed 3 January 2023.

This represents a slight change in focus. As recently as 2019, Kamlesh Nilkanth Vyas, then the Chairman of India's Atomic Energy Commission, had argued that SMRs should not be prioritized because they require additional development to address technological gaps.[1389] The importance of larger size reactors continues to be a priority for the DAE, as stated in India's parliament in August 2023; however, the same parliament statement also announced that "detailed technical discussions are currently underway to plan a roadmap for studying the feasibility and effectiveness of deployment of such reactors".[1390] The change of focus might be a result of the stagnation of nuclear power in the country.

RUSSIA

Several Russian design organizations or companies, including Afrikantov Experimental Design Bureau for Mechanical Engineering (OKBM), NA Dollezhal Research and Development Institute of Power Engineering (Nikiet), and AKME Engineering, have been developing SMR designs.[1391] Because of Russia's experience with using nuclear power for marine propulsion, including submarines and icebreaker ships, there is a focus on barge mounted reactors for coastal locations. The first such project based on the KLT-40S design, a pressurized light water reactor, is operational. Another project based on a fast neutron reactor design is under construction.

Light Water Reactor Designs

The first SMR design to be deployed in Russia is the "floating" KLT-40S design. Two KLT-40S SMRs, loaded on a barge called the Akademik Lomonosov, were commissioned in May 2020 in the eastern part of the country. As earlier WNISR editions have discussed, this project suffered lengthy delays and cost overruns and the operating records of the two KLT-40S reactors have been quite poor. According to the IAEA's PRIS database, the two reactors had load factors of just 26.4 and 30.5 percent respectively in 2022, and lifetime load factors of just 34 and 22.4 percent. The reasons for the mediocre power-generation performance remain unclear.

The second SMR based on light water reactor design that is to be constructed is the 55 MW RITM-200S, which is based on the RITM-200 series used in nuclear-powered icebreaker ships. Keel laying for the barge—considered as the equivalent of construction start for floating reactors—that is to hold two RITM-200S reactors commenced in August 2022.[1392] The barge is

1389 - Manpreet Sethi, "Assessing The Promise Of Small Modular Reactors From An Indian Perspective", Asia-Pacific Leadership Network, 25 July 2022, see https://www.apln.network/news/member_activities/assessing-the-promise-of-small-modular-reactors-from-an-indian-perspective, accessed 18 July 2023.

1390 - Lok Sabha, "Unstarred Question No. 2193 to Be Answered on 02.08.2023 - Small Modular Reactor", Department of Atomic Energy, Answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions, Prime Minister's Office, Government of India, 2 August 2023, see https://sansad.in/getFile/loksabhaquestions/annex/1712/AU2193.pdf?source=pqals, accessed 6 November 2023.

1391 - Vladimir Kuznetsov, "Small modular reactors (SMRs): The case of Russia", in "Handbook of Small Modular Nuclear Reactors", Second Edition, ed. by Mario D. Carelli, *Woodhead Publishing*, 2021, see https://www.sciencedirect.com/science/article/pii/B9780128239162000199, accessed 19 June 2023.

1392 - Rosatom, "Keel-laying ceremony for the first Arctic-type Floating Power Unit with RITM-200 transport reactor vessels", Press Release, 30 August 2022, see https://rosatom-mena.com/press-centre/news/keel-laying-ceremony-for-the-first-arctic-type-floating-power-unit-with-ritm-200-transport-reactor-v/, accessed 5 October 2022.

being built in China, by Wison (Nantong) Heavy Industries, which won the contract in 2021 to build two of these barges at a reported price of US$226 million.[1393]

Russia's nuclear regulatory body, Rostekhnadzor, also issued a construction license for the RITM-200N reactor in April 2023.[1394] The project site is in Yakutia, in the Arctic region of the country.

Fast Neutron Reactor Designs

Russia is also constructing SMR designs based on fast neutron technology. The first of these, the lead cooled BREST-300, was developed by the NA Dollezhal Research and Development Institute of Power Engineering (Nikiet) and is under construction at the Siberian Chemical Combine (SCC) in Seversk.[1395] When construction started in June 2021, the reactor was expected to begin to operate "before the end of 2026",[1396] and the cost of the reactor, according to one source, was 100 billion rubles (US$1.3 billion at 2021 conversion rates).[1397] So far, there is no announced delay to that schedule. According to remarks by the Director of Rosatom's Industry Centre for Capital Construction on the sidelines of a conference in October 2022, construction of the BREST-300 was seven months ahead of schedule.[1398] However, as discussed in WNISR2022, the BREST-300 project is significantly delayed when viewed in terms of earlier expectations; for example, the slides of a 2013 presentation from the Technical Lead of the IAEA's SMR Technology Development division showed the BREST-300 was expected to be deployed by 2018.[1399]

SMRs are part of Rosatom's export plans. In June 2023, at the XXVI St. Petersburg International Economic Forum, Alexey Likhachev, Director General of Rosatom, stated

> Small capacity does not weigh much in the indicators, but it is important for us. Small-scale power units, probably of modular design, will become the reference platform for subsequent export. The global nuclear power engineering market is being rearranged now, and real plant models are important.[1400]

1393 - Amber Wang, "First Chinese firm wins contract for Russian floating nuclear power project", *South China Morning Post*, 16 September 2021, see https://www.scmp.com/news/china/diplomacy/article/3148884/first-chinese-firm-wins-contract-russian-floating-nuclear, accessed 8 August 2023.

1394 - *WNN*, "Licence issued for Russia's first land-based SMR", *World Nuclear News*, 24 April 2023, see https://www.world-nuclear-news.org/Articles/Licence-issued-for-Russia-s-first-land-based-SMR, accessed 25 April 2023.

1395 - Darrell Proctor, "Nuclear First—Work Starts on Russian Fast Neutron Reactor", *POWER Magazine*, 8 June 2021, see https://www.powermag.com/nuclear-first-work-starts-on-russian-fast-neutron-reactor/, accessed 27 June 2021.

1396 - *WNN*, "Foundation set in place for BREST reactor", 24 August 2021, see https://world-nuclear-news.org/Articles/Foundation-set-in-place-for-BREST-reactor, accessed 1 August 2022; and Rosatom, "ROSATOM starts construction of unique power unit with BREST-OD-300 fast neutron reactor", Press Release, 8 June 2021, see https://rosatom.ru/en/press-centre/news/rosatom-starts-construction-of-unique-power-unit-with-brest-od-300-fast-neutron-reactor/, accessed 8 August 2023.

1397 - *Time News*, "Construction of the BREST reactor for 100 billion rubles began near Tomsk", 20 June 2021, see https://time.news/construction-of-the-brest-reactor-for-100-billion-rubles-began-near-tomsk/, accessed 15 September 2023.

1398 - *NEI Magazine*, "Construction of Russia's Brest-300 reactor ahead of schedule", *Nuclear Engineering International*, 14 October 2022, see https://www.neimagazine.com/news/newsconstruction-of-russias-brest-300-reactor-ahead-of-schedule-10085878, accessed 19 June 2023.

1399 - M. Hadid Subki, "Global Development Trends, Prospects and Issues for SMRs Deployment", presented at the 23rd Meeting of the Technical Working Group on Gas Cooled Reactors (TWG-GCR), 5 March 2013.

1400 - Rosatom, "A plenary session devoted to the nuclear industry role in technological sovereignty assurance was held at SPIEF-2023 with the support of ROSATOM", Press Release, 16 June 2023, see https://rosatom.ru/en/press-centre/news/a-plenary-session-devoted-to-the-nuclear-industry-role-in-technological-sovereignty-assurance-was-he/?sphrase_id=4459042, accessed 10 September 2023.

In January 2023, Rosatom and Kyrgyzstan's Minister of Energy each announced that Rosatom is studying sites in Kyrgyzstan for the possible construction of a nuclear plant with two RITM-200N reactor units with a capacity of 55 MW each.[1401] Earlier, in November 2022, Myanmar's Ministry of Electrification signed an MoU with Rosatom on "conducting a joint pre-feasibility study on NPP construction in Myanmar using Russian [SMR] technologies".[1402] And, in January 2022, Rosatom signed an agreement with Armenia; the announcement is ambiguous about whether Rosatom was seeking to export large or small reactors, but it being signed on the sidelines of "the Russian Day of SMR NPPs (Small Modular Reactor Nuclear Power Plants)" event held at Expo 2020 in Dubai suggests that an SMR might be under consideration.[1403]

SOUTH KOREA

South Korea has long been developing the System-Integrated Modular Advanced Reactor (SMART), a 100-MW pressurized water reactor design (see earlier WNISR editions). More recently, several other designs have been initiated, including a smaller capacity (70 MW thermal) light-water design called Advanced Reactor for Multipurpose Research Applications (ARA), the innovative SMR (i-SMR), a molten salt reactor, and a sodium cooled fast reactor (SFR).[1404]

The experience with the SMART design offers a sense of the challenges confronting these designs. Because of its adverse economics, with a "target overnight plant construction cost" of a first of a kind plant being estimated at US$10,000/kW(e),[1405] there have been no orders for the SMART reactor, even though the design has been licensed for over a decade. As a result, Korea Hydro and Nuclear Power (KHNP) announced in April 2021 that it is "carrying out a project to improve" the SMART design, with the aim of obtaining "a license for the improved SMART by 2028".[1406]

Dubbed the "i-SMR" for "innovative SMR", the new reactor design is to generate 170 MW of electricity, with each plant involving four reactors.[1407] Thus, the strategy evidently relies at least in part on economies of scale to deal with the problems confronting the SMART design. In July 2023, the Ministries of Trade, Industry and Energy, and Science and ICT announced the

1401 - *NEI Magazine*, "Rosatom studies sites in Kyrgyzstan for small NPP", *Nuclear Engineering International*, 25 January 2023, see https://www.neimagazine.com/news/newsrosatom-studies-sites-in-kyrgyzstan-for-small-npp-10541341, accessed 15 September 2023.

1402 - *NEI Magazine*, "Russia and Myanmar expand nuclear cooperation", *Nuclear Engineering International*, 4 July 2023, see https://www.neimagazine.com/news/newsrussia-and-myanmar-expand-nuclear-cooperation-10983631, accessed 15 September 2023.

1403 - Rosatom, "Rosatom and Armenia Sign Cooperation Agreement to Build New Nuclear Units", Press Release, 20 January 2022, see https://rosatom-southasia.com/press-centre/news/rosatom-and-armenia-sign-cooperation-agreement-to-build-new-nuclear-units/, accessed 10 September 2023.

1404 - Stephanie Cooke, "Kaeri's ARA SMR Push Raises Eyebrows", *Energy Intelligence*, 3 December 2021, see https://www.energyintel.com/0000017d-76b3-d7ae-a37d-7ebfa1db0000, accessed 1 August 2022; and Charles Lee, "South Korea companies develop molten salt reactor for shipping, power generation", S&P Global Platts, 22 June 2021, see https://www.spglobal.com/platts/en/market-insights/latest-news/metals/062221-south-korea-companies-develop-molten-salt-reactor-for-shipping-power-generation, accessed 23 June 2021.

1405 - IAEA, "Advances in Small Modular Reactor Technology Developments—A Supplement to IAEA Advanced Reactors Information System (ARIS) 2020 Edition", International Atomic Energy Agency, September 2020, p. 56, see https://aris.iaea.org/Publications/SMR_Book_2020.pdf, accessed 8 August 2023.

1406 - Jung Min-hee, "KHNP to Accelerate Development of Innovative SMRs", *Businesskorea*, 20 April 2021, see http://www.businesskorea.co.kr/news/articleView.html?idxno=65179, accessed 24 June 2021.

1407 - IAEA, "Advances in Small Modular Reactor Technology Developments—A Supplement to: Advanced Reactors Information System (ARIS) 2022 Edition", September 2022, op. cit.

launch of a project worth KRW399 billion (US$303 million) to establish the "Innovative [SMR] Technology Development Project" with the goal of obtaining the Standard Design Approval by 2028.[1408] The same month, 42 state-run and private entities came together to create a public-private partnership "to advance Korea's [SMR] sector".[1409]

Despite these groups being formed, there is some evidence that prospects for Korean SMRs are not great. This might explain why South Korean companies and financial institutions are entering into agreements with U.S. SMR developers like NuScale, TerraPower, and Holtec.[1410] Also, earlier this year, a Korean company, GS Energy, has signed a Memorandum of Understanding with Uljin County to consider importing a nuclear plant with six NuScale SMR units.[1411] While problems with Korean SMRs is one reason for this proposal, NuScale's own financial woes and its then-floundering (and now cancelled) Carbon Free Power Project might also be an incentive for NuScale to explore other projects as soon as possible.[1412]

Although there were many announcements about exporting SMART reactors to Saudi Arabia and other middle eastern countries that have been covered in earlier WNISR editions, South Korea currently seems to be focused only on exports of the large APR-1400 reactor design.

UNITED KINGDOM

The United Kingdom's interest in SMRs follows a 2014 feasibility study carried out by the government's National Nuclear Laboratory and funded by seven nuclear organizations, including Rolls Royce.[1413] Rolls Royce then followed it up in 2017 with announcing that it had designed an SMR, which was initially rated at 440 MW of electricity[1414], i.e., not really meeting the definition of a small reactor. By 2021 that was further uprated to 470 MW, and its Chief Technical Officer traced the increase to a desire "to minimise the cost of energy coming out… the cost being the historical challenge of nuclear power".[1415] In February 2021, Rolls-Royce projected that it would complete the Generic Design Assessment (GDA) review "in about 2024" and would start generating power for the grid "in about 2030 for the first SMR".[1416] The Office of

1408 - *Yonhap*, "Korea launches project team to foster small modular reactor", *The Korea Times*, 10 July 2023, see https://www.koreatimes.co.kr/www/tech/2023/07/419_354648.html, accessed 18 July 2023; and MOTIE, "Korea kicks off Project Team for innovative SMRs", Press Release, Ministry of Trade, Industry and Energy, 14 July 2023, see https://english.motie.go.kr/en/pc/pressreleases/bbs/bbsView.do?bbs_cd_n=2&bbs_seq_n=1358, accessed 8 August 2023.

1409 - *WNN*, "South Korea forms SMR Alliance", *World Nuclear News*, 5 July 2023, see https://www.world-nuclear-news.org/Articles/South-Korea-forms-SMR-Alliance, accessed 15 July 2023.

1410 - *WNN*, "Expansion of US-Korean cooperation on SMRs", *World Nuclear News*, 26 April 2023, see https://world-nuclear-news.org/Articles/Expansion-of-US-Korean-cooperation-on-SMRs; and *Nuclear Newswire*, "Holtec deepens relationship with South Korea for SMR deployment", American Nuclear Society, 4 May 2023, see https://www.ans.org/news/article-4971/holtec-deepens-relationship-with-south-korea-for-smr-deployment/; both accessed 15 September 2023.

1411 - *WNN*, "Korea considers deployment of NuScale SMR for hydrogen production", *World Nuclear News*, 10 May 2023, see https://www.world-nuclear-news.org/Articles/Korea-considers-deployment-of-NuScale-SMR-for-hydr, accessed 11 May 2023.

1412 - M. V. Ramana and Seok Kwanghoon, "The hype and the reality of small modular reactors", *The Hankyoreh*, 25 May 2023, see https://english.hani.co.kr/arti/english_edition/english_editorials/1093347.html, accessed 8 August 2023.

1413 - *WNN*, "National Nuclear Laboratory urges UK investment in SMRs", *World Nuclear News*, 4 December 2014, see https://www.world-nuclear-news.org/NN-National-Nuclear-Laboratory-urges-UK-investment-in-SMRs-4121401.html, accessed 6 July 2019.

1414 - Rolls-Royce, "UK SMR: A National Endeavour", September 2017, see https://nuclear.foe.org.au/wp-content/uploads/Rolls-Royce-2017-SMR-national-endeavour-see-p22.pdf, accessed 6 July 2019.

1415 - *WNN*, "Rolls-Royce on track for 2030 delivery of UK SMR", *World Nuclear News*, 11 February 2021, see https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR, accessed 27 June 2021.

1416 - Ibidem.

Nuclear Regulation (ONR) accepted it for GDA review in March 2022 and started the process in the following month. The process is being carried out together with the Environment Agency and Natural Resources Wales. The first phase of a three-phase review has been completed and ONR has moved to the next phase of its assessment.[1417] According to ONR, the full process is expected to be completed "in August 2026", but ONR specified that "Progression from Step 2 to 3 is subject to the RP [Requesting Party, i.e. Rolls-Royce] securing additional funding during Step 2".[1418]

In addition to Rolls-Royce, six other SMR designs have been submitted for approval:[1419]

- GE Hitachi's BWRX-300 boiling water reactor,
- Holtec's SMR-160 pressurized water reactor,
- X-energy's high-temperature gas cooled reactor,
- Newcleo's lead-cooled fast reactor,
- Copenhagen Atomics's thorium molten salt reactor, and
- a Cumbrian engineering group called GMET, which said it is developing a small reactor called NuCell but has not even specified what kind of reactor design it is.

The U.K. 2023 Spring Budget announced that the government was launching Great British Nuclear (GBN), the organization that is to "address constraints in the nuclear market and support new nuclear builds",[1420] (see United Kingdom Focus). In turn, GBN was to launch a competition for SMRs. Its promise for the successful SMR project is to offer support "to be ready to enable a Final Investment Decision (FID) by 2029".[1421] In other words, there might not be large amounts of money from the government to support the building of SMRs until close to the end of this decade.

In July 2023, the U.K. government announced that it will be offering "a grant funding package totaling up to £157 million [US$199 million]" which includes "up to £77.1 million [US$98 million] of funding for companies to accelerate advanced nuclear business development in the UK and support advanced nuclear designs" and "up to £58 million [US$73 million] funding for the further development and design of a type of advanced modular reactor (AMR) and next generation fuel".[1422] That includes:

1417 - ONR, "Rolls-Royce SMR design progresses to next step of Generic Design Assessment", Press Release, Office for Nuclear Regulation, 3 April 2023, see https://news.onr.org.uk/2023/04/rolls-royce-smr-design-progresses-to-next-step-of-generic-design-assessment/, accessed 3 April 2023.

1418 - ONR, "Step 1 GDA statement for the Rolls-Royce SMR", Office for Nuclear Regulation, 3 April 2023, see https://www.onr.org.uk/new-reactors/rolls-royce/step-1-statement-of-findings.htm, accessed 18 July 2023.

1419 - *Professional Engineering*, "SMR developers submit 6 designs for UK approval", Institution of Mechanical Engineers, 6 January 2023, see https://www.imeche.org/news/news-article/smr-developers-submit-6-designs-for-uk-approval, accessed 16 July 2023.

1420 - HM Treasury, "Spring Budget 2023", Policy Paper 1183, U.K. Government, Updated 21 March 2023, see https://www.gov.uk/government/publications/spring-budget-2023/spring-budget-2023-html, accessed 3 August 2023.

1421 - Great British Nuclear, "Small Modular Reactors: competitive technology selection process", 19 July 2023, s ee https://www.gov.uk/guidance/small-modular-reactors-competitive-technology-selection-process, accessed 3 August 2023.

1422 - Department for Energy Security and Net Zero, Great British Nuclear, and Nuclear Decommissioning Authority, "British nuclear revival to move towards energy independence", Press Release, U.K. Government, 18 July 2023, see https://www.gov.uk/government/news/british-nuclear-revival-to-move-towards-energy-independence, accessed 19 July 2023.

- "up to £22.5 million [US$28.5 million] to Ultra Safe Nuclear Corporation" to develop "a high temperature micro modular reactor"; and
- "up to £31 million [US$39 million] to the U.K.'s National Nuclear Laboratory" to "accelerate the design of a high temperature reactors"; as well as
- "over £1.2 million [US$1.5 million] to support MoltexFLEX", a molten salt reactor design, to "build and operate rigs for the development of molten salt fuel".

In other words, nearly all the funding is focused on high temperature gas cooled reactors.

Conspicuously missing in the announcement is Rolls-Royce. This is surprising because the consortium it belonged to did receive £18 million (US$$_{2019}$23 million) in 2019 from UK Research and Innovation.[1423] And in November 2021, Rolls-Royce announced that it had received £210 million (~US289_{2021}$ million) in government funding.[1424] Earlier, in February 2023, the new head of Rolls-Royce, Tufan Erginbilgic, called upon the government to "engage in talks" about its reactor design, including to "sign an agreement for the deployment of the first project".[1425] Erginbilgic explained that rivals were working on similar technology and so it was important "that we engage therefore with the UK government urgently, and for a project that we can deploy as soon as possible".[1426]

In addition to government funding, Rolls-Royce has raised £280 million (US$$_{2021}$385 million) in private funds.[1427] Despite all this investment, in February 2023, Rolls-Royce claimed that "by December 2024" the money will have run out.[1428] By May 2023, the media was speculating that Erginbilgic might be getting ready to abandon the SMR project and other "costly side bets" and focus on its core business of "making aero engines and diesels".[1429] Whether this will really happen, or if this is a strategy to get more government funding remains to be seen.

UNITED STATES

Even though there is still no SMR under construction in the country, the United States government continues to actively promote these unproven technologies, usually resorting to the argument that they are required for climate change mitigation. During the 27th U.N. Climate Conference (COP27), President Joe Biden announced various initiatives to position the

1423 - *WNN*, "UK commits funding to Rolls-Royce SMR", *World Nuclear News*, 23 July 2019, see http://world-nuclear-news.org/Articles/UK-commits-funding-to-Rolls-Royce-SMR, accessed 23 July 2019.

1424 - Phil Chaffee, "Newbuild: Financing the SMRs of Rolls-Royce, GE and NuScale", *Nuclear Intelligence Weekly*, 12 November 2021.

1425 - Jacob Paul, "Rolls-Royce warns UK risks slowing pace of new nuclear plant rollout", *Express*, 24 February 2023, see https://www.express.co.uk/news/science/1739196/rolls-royce-smr-nuclear-energy-Tufan-Erginbilgic-reactors, accessed 2 August 2023.

1426 - Susanna Twidale, "UK's Rolls-Royce small nuclear program to run out of cash by end-2024", *Reuters*, 28 February 2023, see https://www.reuters.com/article/rolls-royce-hldg-nuclear-idUKKBN2V216V, accessed 7 October 2023.

1427 - David Dalton, "Qatar Invests £85 Million In Rolls-Royce SMR Project", *NucNet*, as published on *Neutron Bytes*, 22 December 2021, see https://neutronbytes.com/2021/12/22/qatar-invests-85-million-in-rolls-royce-smr-project/, accessed 2 August 2022; and Phil Chaffee, "Newbuild: Financing the SMRs of Rolls-Royce, GE and NuScale", *Nuclear Intelligence Weekly*, 12 November 2021.

1428 - Susanna Twidale, "UK's Rolls-Royce Small Nuclear Program to Run out of Cash by End-2024", *Reuters*, 28 February 2023, op. cit.

1429 - Howard Mustoe, "The 'ruthless' axeman carving out a new future for Rolls-Royce", *The Telegraph*, 28 May 2023, see https://www.telegraph.co.uk/business/2023/05/28/rolls-royce-tufan-erginbilgic/, accessed 31 May 2023.

United States as a leader in tackling climate change, including two projects involving SMRs.[1430] One initiative aims to fund feasibility studies and supporting activities to examine a possible transition in Europe from coal-fired plants to SMRs. The second one is a "2-year Ukraine Clean Fuels from SMRs Pilot demonstration project in Ukraine" mainly to "efficiently produce clean hydrogen fuels from SMR and cutting-edge electrolysis technologies". The latter is particularly remarkable both for the choice of location—Ukraine, which continues to be battling Russia as of the time of this writing—and the time frame (two years), which is a blink of an eye when it comes to nuclear projects of any kind.

Among the projects envisioned for conversion from coal to nuclear is the Doicesti plant in Romania. At the G7 Leaders' Summit in May 2023, U.S. President Biden announced

> public-private support for the Romania small modular reactor (SMR) project from the United States, Japan, Republic of Korea, and United Arab Emirates of up to [US]$275 million, which includes a Letter of Interest from U.S Export-Import Bank (EXIM) for up to [US]$99 million from the EXIM Engineering Multiplier Program. In addition, EXIM and U.S. International Development Finance Corporation (DFC) issued Letters of Interest for potential support of up to [US]$3 billion and [US]$1 billion, respectively, for project deployment.[1431]

Earlier, in June 2022, at the G7 Leaders' Summit, President Biden announced a US$14 million commitment to carry out "a Front-End Engineering and Design (FEED) study", which is described as "the next step in fulfilling the pledge made by Special Presidential Envoy for Climate John Kerry and Romania President Klaus Iohannis at the 2021 United Nations Conference on Climate Change in Glasgow (COP26), where they announced their intent to deploy an SMR in Romania in partnership with U.S. firm NuScale Power".[1432]

The May 2023 announcement claimed that the various investments would result in the deployment of a NuScale reactor "in 2029" because it would "capitalize on the experience gained on the first SMR project under development in the United States at the Carbon Free Power Project in Idaho".[1433] However, as discussed below, the Carbon Free Power Project was abandoned in November 2023[1434] because of unfavorable economics. There is no reason to expect the economics of a NuScale SMR in Europe to fare any better.

1430 - The White House, "Fact Sheet: President Biden Announces New Initiatives at COP27 to Strengthen U.S. Leadership in Tackling Climate Change", Press Release, U.S. Government, 11 November 2022, see https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/11/fact-sheet-president-biden-announces-new-initiatives-at-cop27-to-strengthen-u-s-leadership-in-tackling-climate-change/, accessed 2 August 2023.

1431 - U.S. Department of State, "The United States and Multinational Public-Private Partners Look to Provide Up To $275 Million to Advance the Romania Small Modular Reactor Project; United States Issues Letters of Interest for Up To $4 Billion in Project Financing", Press Release, United States Government, 20 May 2023, see https://www.state.gov/the-united-states-and-multinational-public-private-partners-look-to-provide-up-to-275-million-to-advance-the-romania-small-modular-reactor-project-united-states-issues-letters-of-interest-for-up-to/, accessed 7 October 2023.

1432 - U.S. Department of State, "United States Takes Next Step in Supporting Innovative Clean Nuclear Technology in Europe", Press Release, United States Government, 26 June 2022, see https://www.state.gov/united-states-takes-next-step-in-supporting-innovative-clean-nuclear-technology-in-europe/, accessed 7 October 2023.

1433 - U.S. Department of State, "The United States and Multinational Public-Private Partners Look to Provide Up To $275 Million to Advance the Romania Small Modular Reactor Project; United States Issues Letters of Interest for Up To $4 Billion in Project Financing", May 2023, op. cit.

1434 - NuScale, "Utah Associated Municipal Power Systems (UAMPS) and NuScale Power Agree to Terminate the Carbon Free Power Project (CFPP)", Press Release, 8 November 2023, see https://nuscale-prod-pbpdt9uqe-nuscale-power.vercel.app/en/news/press-releases/2023/uamps-and-nuscale-power-agree-to-terminate-the-carbon-free-power-project; and Timothy Gardner and Manas Mishra, "NuScale ends Utah project, in blow to US nuclear power ambitions", *Reuters*, 9 November 2023, see https://www.reuters.com/business/energy/nuscale-power-uamps-agree-terminate-nuclear-project-2023-11-08/; both accessed 17 November 2023.

In January 2023, the U.S. Nuclear Regulatory Commission (NRC) issued a conditional generic design certification for a 50-MW NuScale reactor design.[1435] As detailed in earlier WNISR editions, over the course of this certification process, the NRC identified many unresolved problems (or "issues", as the NRC euphemistically terms them). An important problem is the stability of the steam generator,[1436] a concern that was first highlighted by the NRC's Advisory Committee on Reactor Safeguards in 2020.[1437]

The irony is that NuScale is no longer interested in building a 50 MW design. Indeed, the products section of NuScale's website does not even list a 50 MW design.[1438] The output of NuScale's SMR design has increased twice since it submitted the 50 MW design to the NRC for certification—first to 60 MW,[1439] and then to 77 MW per module.[1440] NuScale is planning to build only the 77 MW design in all the first projects that are under discussion, whether it is in the United States, in Romania, or in Bulgaria.[1441]

In order to construct this new design, NuScale needs approval from the NRC. On 1 January 2023, NuScale submitted an application for a standard design approval to the NRC for the 77 MW design.[1442] Rather than applying for a design certification, NuScale has notably chosen to apply only for a standard design approval.[1443] The latter is "a quasi-final regulatory decision" in contrast to a design certification which "is considered a final regulatory decision".[1444]

Earlier, on 15 November 2022 the NRC staff wrote to NuScale after reviewing the company's "preapplication documents", highlighting 99 "significant" observations, including a variety

1435 - U.S. NRC, "NuScale Small Modular Reactor Design Certification", Federal Register, Vol. 88, No. 12, United States Nuclear Regulatory Commission, 19 January 2023, effective 21 February 2023, see https://www.federalregister.gov/documents/2023/01/19/2023-00729/nuscale-small-modular-reactor-design-certification, accessed 3 February 2023.

1436 - U.S. NRC, "RIN 3150-AJ98—NuScale Small Modular Reactor Design Certification", Final Rule, NRC-2017-0029, U.S. Nuclear Regulatory Commission, 2022, see https://www.nrc.gov/docs/ML2200/ML22004A005.pdf, accessed 7 August 2022.

1437 - Jessica Sondgeroth, "A Pox on NuScale's SMR Design Certification", *Nuclear Intelligence Weekly*, 15 May 2020, see https://www.energyintel.com/0000017b-a7da-de4c-a17b-e7da9db70000, accessed 16 May 2020.

1438 - NuScale Power, "Products—Clean Energy Solutions", 2023, see https://nuscale-prod-a3qyb07y7-nuscale-power.vercel.app/products, accessed 2 August 2023.

1439 - NuScale Power, "Breakthrough for NuScale Power; Increase in its SMR Output Delivers Customers 20 Percent More Power", Press Release, 6 June 2018, see https://www.nuscalepower.com/en/news/press-releases/2018/increase-in-its-smr-output-delivers-customers-20-percent-more-power, accessed 27 June 2021.

1440 - NuScale, "NuScale Power Announces an Additional 25 Percent Increase in NuScale Power Module™ Output; Additional Power Plant Solutions", Press Release, 10 November 2020, see https://www.nuscalepower.com/en/news/press-releases/2020/nuscale-power-announces-an-additional-25-percent-increase-in-nuscale-power-module-output, accessed 10 November 2020.

1441 - Michael McAuliffe, "UAMPS to go with six-unit NuScale SMR plant, smaller than original", *Nucleonics Week*, 22 July 2021; and *WNN*, "NuScale SMR to be evaluated for use in Bulgaria", 17 February 2021, see https://world-nuclear-news.org/Articles/NuScale-SMR-to-be-evaluated-for-use-in-Bulgaria; also Nuclearelectrica, "Nuclearelectrica & NuScale working meeting following the $14 million grant announced by President Biden for the development of small modular reactors (SMRs) in Romania", Press Release, 2022, see https://www.nuclearelectrica.ro/2022/07/06/nuclearelectrica-nuscale-working-meeting-following-the-14-million-grant-announced-by-president-biden-for-the-development-of-small-modular-reactors-smrs-in-romania/?lang=en; all accessed 8 July 2022.

1442 - New Reactor Licensing Branch, "Acceptance Review of the NuScale US460 Standard Design Approval Application (Docket Nos. 05200050 and 99902078)", Division of New and Renewed Licenses, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, addressed to NuScale Power, LLC, 17 March 2023, see https://www.nrc.gov/docs/ML2305/ML23058A160.pdf, accessed 9 August 2023.

1443 - Arjun Makhijani and M. V. Ramana, "Questions for NuScale VOYGR Reactor Certification: When Will It Be Done? And then, Will It Be Safe?", Environmental Working Group, 9 April 2023, see https://static.ewg.org/upload/pdf/FINAL_NuScale_analysis_for_EWG.pdf, accessed 20 July 2023.

1444 - Jacopo Buongiorno et al., "The Future of Nuclear Power in a Carbon-Constrained World", Revision 1, MIT Energy Initiative, Massachusetts Institute of Technology, 2018, see https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf, accessed 24 September 2018.

of concerns.[1445] This included six "challenging and/or significant issues" that could affect acceptance of the certification application and/or "be focus areas for…safety review", with two concerning steam generators.[1446] The problems with the NuScale design's proposed steam generators have been known since early 2020.

Alongside the increase in the design output of the reactor has been a disproportionate increase in costs. In November 2021, the CEO of the Utah Associated Municipal Power Systems (UAMPS) that was to build the first NuScale plant, estimated the cost of this revised project at US$5.32 billion.[1447] In December 2021, UAMPS officially down-sized its plan "from 12 NuScale Power Modules to 6 modules".[1448] But one year later, on 2 January 2023, UAMPS released a new cost estimate of US$9.3 billion for the same project.[1449] As a per unit of installed capacity, that cost estimate amounts to US$20,000/kW around 250 percent more than the initial per kilowatt cost estimate for the Vogtle project in Georgia, when it was still on paper and had not exploded in cost during construction.[1450]

Despite the problems with the NuScale design and the high cost, UAMPS was apparently going ahead with its plans to build six modules in Idaho and on 1 August 2023, reportedly submitted an application to the NRC to start early construction activities in mid-2025. Commercial operation of the first module was planned for 2029 with all modules in commercial operation by 2030.[1451] Then, in a complete reversal, on 8 November 2023, UAMPS and NuScale announced that they have "mutually agreed to terminate the Carbon Free Power Project (CFPP)", the only commercial SMR project in the western world. The main reason given was that "it appears unlikely that the project will have enough subscription to continue toward deployment".[1452] The following day, NuScale, the only listed company specializing on SMRs, lost one third of its remaining stock value. Since its peak in August 2022, the company lost 86 percent of its value.[1453]

1445 - Division of New and Renewed Licenses "Preapplication readiness assessment report of the Nuscale, Power, LLC Standard Design Approval Draft Application—Docket No. 99902078", Office of Nuclear Reactor Regulation, United States Nuclear Regulatory Commission, 15 November 2022, see https://s3.documentcloud.org/documents/23321003/nuscale-sdaa-preapplication-readiness-assessment-summary-observation-report-final-4.pdf, accessed 23 December 2022.

1446 - Arjun Makhijani and M. V. Ramana, "Questions for NuScale VOYGR Reactor Certification: When Will It Be Done? And Then, Will It Be Safe?", April 2023, op. cit.

1447 - Douglas O. Hunter, "Why the world is watching Utah's Carbon Free Power Project", *The Salt Lake Tribune*, 23 November 2021, see https://www.sltrib.com/opinion/commentary/2021/11/23/douglas-o-hunter-why/, accessed 20 December 2021.

1448 - UAMPS, "December Carbon Free Power Project Update", Utah Associated Municipal Power Systems, *Clean Energy News*, 28 December 2021, see https://www.uamps.com/File/9ebafobf-4d0a-4073-9ba4-c6e63cdc44c4, accessed 7 August 2022.

1449 - UAMPS, "Talking Points", Utah Associated Municipal Power Systems, 2 January 2023, see https://ieefa.org/sites/default/files/2023-01/UAMPS%20Talking%20Points%20_%20Class%203%20_%2020230102%20_%20Final.pdf, accessed 9 August 2023.

1450 - Arjun Makhijani and M. V. Ramana, "Questions for NuScale VOYGR Reactor Certification: When Will It Be Done? And Then, Will It Be Safe?", April 2023, op. cit.

1451 - *WNN*, "First part of Idaho SMR licence application submitted", 1 August 2023, see https://www.world-nuclear-news.org/Articles/First-part-of-Idaho-SMR-licence-application-submit?feed=feed, accessed 1 August 2023; and UAMPS, "CFPP Update", Utah Associated Municipal Power Systems, *Clean Energy News*, August 2023, see https://www.uamps.com/File/925f9a02-c227-4474-8ce8-76474a5fc5e5, accessed 6 November 2023.

1452 - NuScale, " Utah Associated Municipal Power Systems (UAMPS) and NuScale Power Agree to Terminate the Carbon Free Power Project (CFPP)", Press Release, 8 November 2023, see https://nuscale-prod-pbpdt9uqe-nuscale-power.vercel.app/en/news/press-releases/2023/uamps-and-nuscale-power-agree-to-terminate-the-carbon-free-power-project, accessed 9 November 2023.

1453 - See *Yahoo! Finance*, "NuScale Power Corporation (SMR)", as of 9 November 2023, see https://fr.finance.yahoo.com/quote/SMR, accessed 9 November 2023.

CONCLUSION

Small Modular Reactors, by virtue of the fact that they are designed to generate less electricity than standard reactor designs, will necessarily face greater economic challenges.[1454] When compared to large reactors, SMRs will be more expensive per unit of installed capacity and produce more costly power. The trend of SMR designers to move towards larger design outputs—South Korea moving from a 100 MW design to a 170 MW design, Rolls-Royce proposing a 470 MW design—offers evidence for the continued importance of economies of scale. However, even after increasing output power, SMRs remain uneconomical. The case of NuScale, with a cost estimate of around US$20,000 per kW of installed capacity, illustrates how expensive SMRs could be.

All SMR designs are being developed with large amounts of public money. The puzzle remains why governments continue to invest in a suite of technologies that appear doomed to commercial failure.

1454 - Stephen Thomas and M. V. Ramana, "A hopeless pursuit? National efforts to promote small modular nuclear reactors and revive nuclear power", *WIREs Energy and Environment*, 12 January 2022, see https://onlinelibrary.wiley.com/doi/abs/10.1002/wene.429, accessed 31 January 2022.

NUCLEAR ECONOMICS AND FINANCE

Facing Persistent Competitive Pressures, Nuclear Relies on Increasing State Support

OVERVIEW

This chapter provides an overview of the financial performance of existing reactors and the economics of new construction. Government policies and state ownership of reactors and fuel chain facilities are increasingly important drivers of industry investment and activity. These policies affect the economics of both operating reactors and new build projects, in the latter category often focused on subsidizing the cost of capital. Utility operators continue to face economic challenges in competitive power markets, and from declining costs of competing energy technologies and increasing ability to reduce, reshape, or time-shift loads on the demand side. The rising share of renewables, along with growing opportunities to manage demand, are already eroding the economics of providers such as nuclear which rely on continuous revenue-generating operation at high load factors. These competitive pressures are expected to increase. The economics of emerging themes in the sector, including SMRs and side-services such as hydrogen production and desalination, are explored, as well as certain cost components of nuclear power that are often captured incompletely in cost presentations of the nuclear pathway, artificially bolstering its perceived viability.

This chapter does not evaluate the comparative timelines and costs of different emerging reactor technologies in detail. Nor are climate adaptation costs for existing reactors evaluated, though an increasing frequency and intensity of weather events during the license-extension periods may require investments to adjust for reduced availability of cooling water or cooling capacity in receiving waters.

The nuclear power industry has positioned itself as a critical building block for a decarbonized world. Industry representatives, as well as many national governments, international governmental organizations, and even some major media outlets have vocally advocated for a large buildout of the sector. The *Bloomberg* editorial board, for example, wrote in December 2022 that "[t]he world can't decarbonize without nuclear power…" The IEA's 2022 Net Zero Emissions by 2050 scenario incorporated a doubling of global nuclear capacity to reach 812 GW in 2050, with a newer edition increasing the target to 916 GW "given recent policy support".[1455] Within the United States alone, the U.S. Department of Energy is targeting at least 200 GW of "advanced nuclear" by 2050.[1456] This capacity growth is net of retirements, meaning that the total new build targets need to be even larger, and perhaps much larger given

1455 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, International Energy Agency, September 2022, p.35, see https://iea.blob.core.windows.net/assets/016228e1-42bd-4ca7-bad9-a227c4a40b04/NuclearPowerandSecureEnergyTransitions.pdf, accessed 21 July 2023; IEA, Net Zero Roadmap A Global Pathway to Keep the 1.5 °C Goal in Reach: 2023 Update, September 2023, pp.55, 81, see https://iea.blob.core.windows.net/assets/4ad26550-05c4-4495-9891-98e588cd0be8/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf, accessed 27 September 2023; and IEA, "World Energy Outlook 2023, p. 279, see https://iea.blob.core.windows.net/assets/66b8f989-971c-4a8d-82b0-4735834de594/WorldEnergyOutlook2023.pdf, accessed 6 November 2023.

1456 - U.S. DOE, "Pathways to Commercial Liftoff: Advanced Nuclear", United States Department of Energy, 20 March 2023, p.6, see https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf, accessed 21 July 2023.

that two-thirds of the operating reactors in the world are over 30 years old. Even with likely license extensions, many will have closed by 2050.

Despite optimistic numerical targets for expansion, the proposed role for nuclear in a decarbonized world faces continued competitive pressures on both cost and technical capabilities. This includes the economics of operating reactors and the funding of new ones. Robust growth and cost improvements have continued for renewable energy, particularly wind and solar. Between 2010 and 2021, the global-weighted levelized cost of energy (LCOE) for utility scale PV dropped by nearly 90 percent, by nearly 70 percent for concentrating solar power and onshore wind, and by 60 percent for off-shore wind.[1457] Lazard's U.S.-focused analysis of LCOE shows significant declines since 2009 (83 percent for utility scale solar and 63 percent for onshore wind) as well, despite an uptick in costs during 2022–2023. In contrast, the LCOE for nuclear has *risen* 47 percent over the same period.[1458] Empirically grounded comparisons such as those from Lazard and Bloomberg New Energy Finance consistently show a manyfold and widening LCOE gap between new nuclear generation and the much cheaper renewables, chiefly wind and solar.

The IEA reports capacity additions for renewable electricity (primarily solar PV and wind) of nearly 340 GW in 2022, and more than 150 GW every year since 2016.[1459] In contrast, aggregate new nuclear capacity added during this period was 47 GW.

Capacity additions tell only part of the story, of course, since the global weighted mean load factor for nuclear (81 percent) and fossil (48 percent) are significantly higher than for some renewables such as solar (12 percent) and wind (23 percent). Others, such as geothermal (at 75 percent), have load factors aligned with large fossil-fueled or nuclear plants, traditionally called "baseload" power resources.[1460]

Regional disparities suggest the advantages of one energy resource versus another are not consistent across the world. For example, average nuclear load factors for the 2000–2017 period were only 44 percent in Middle East and North Africa (MENA) countries, whereas wind load factors in the region at 33 percent were higher than the global mean.[1461] Performance of specific projects, such as an offshore wind farm in Scotland, were higher still at 54 percent on average over the past five years.[1462] As a result, competitive opportunities are likely to vary across regions, with public policy, natural endowments, and technical capabilities all playing a role. Further, recent examples of declining load factors for French reactors (only 52 percent in

1457 - IRENA, "Renewable Power Generation Costs in 2021", International Renewable Energy Agency, July 2022, p.15, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf?rev=34c22a4b244d434da0accde7de7c73d8, accessed 21 July 2023.

1458 - Lazard, "LCOE+", April 2023, p.9, see https://www.lazard.com/media/2ozoovyg/lazards-lcoeplus-april-2023.pdf, accessed 21 July 2023.

1459 - IEA, "Renewable Energy Market Update Outlook for 2023 and 2024", International Energy Agency, June 2023, p.16, see https://iea.blob.core.windows.net/assets/63c14514-6833-4cd8-ac53-f9918c2e4cd9/RenewableEnergyMarketUpdate_June2023.pdf, accessed 21 July 2023.)

1460 - Nathanael Bolson, Pedro Prieto and Tadeusz Patzek, "Capacity factors for electrical power generation from renewable and nonrenewable sources", *PNAS*, Vol. 119, No. 52, 20 December 2022, p.1, see https://www.pnas.org/doi/epdf/10.1073/pnas.2205429119, accessed 21 July 2023.

1461 - Ibidem.

1462 - Equinor, "Equinor marks 5 years of operations at world's first floating wind farm", 29 December 2022, see https://www.equinor.com/news/hywind-5-years-world-first-floating-wind-farm, accessed 1 October 2023.

2022, see France Focus) are a reminder of the benefits of diversified supply and a need to plan for potentially higher outage rates as infrastructure ages.

Because the need to scale power generation globally is so huge, there is theoretically ample room for substantial growth in both renewables and nuclear. However, achieving cost-effective nuclear power continues to be a challenge and nuclear power plants continue to be the most expensive construction projects (of any kind) built in many countries (see Table 16).

Table 16 · Most Expensive Construction Projects by Country

Country	Building	Cost (Billion US$)
Saudi Arabia	Masjid Al Haram (Great Mosque)	120.00
United Kingdom	**Hinkley Point C Nuclear Power Plant**	31.00
United States	**Plant Vogtle**	30.00
France	**International Thermonuclear Experimental Reactor (ITER)**	25.00
Turkey	**Akkuyu Nuclear Plant**	20.00
Bangladesh	**Rooppur Nuclear Power Plant**	12.65
Finland	**Olkiluoto 3**	12.40
Slovakia	**Mochovce Nuclear Power Plant**	7.61
Croatia	Željava Air Base	6.00
Singapore	Marina Bay Sands	5.32
China	Wuhan Greenland Center	4.5.0
Macau	Wynn Palace	4.20
South Korea	Lotte World Tower	3.21
UAE	Emirates Palace	3.00
Romania	Palace of the Parliament	3.00
India	Antilia	2.60
Ireland	New Children's Hospital	2.40
Taiwan	Taipei 101	1.80
Russia	Lakhta Center	1.77
Spain	Camp Nou	1.73
Sweden	Nya Karolinska Hospital	1.70
Australia	Crown Sydney	1.68
Germany	Seat of the European Central Bank	1.57
Slovenia	Termoelektrarna Šoštanj blok	1.60
Malaysia	Merdeka 118	1.21
Poland	Bełchatów [Coal] Power Station	1.29

Source: DND, 2023[1463]

Note: This table is only meant to provide orders of magnitude. The numbers have not been vetted by WNISR.

Further, some of the main selling points of nuclear—that it is a firm rather than variable power source (highly questionable in light of recent performances in Belgium, France, Japan, et al.), low-carbon, dispatchable, and generates heat that can be used for other purposes—are all competitive attributes that are, and will continue to be, under pressure from a wide range of

1463 - Mati Ullah Khan, "Emirates Palace: Most Expensive Building In UAE", *Dispatch News Desk*, 26 August 2023, see https://dnd.com.pk/UAE/blog/emirates-palace-most-expensive-building-in-uae/, accessed 1 October 2023.

innovations throughout the system. As Princeton University's Professor Jesse Jenkins recently stated that "there is no base load that we need to meet anymore. In a system with lots of variable renewables, what we need is something that can complement the variable renewables."[1464] The result is that nuclear power is increasingly challenged to produce competitively-priced electricity, when needed, in a market where the operational need or business case for such an inflexible resource with limited load-following capability is weakening. Nuclear's high capital cost makes it particularly expensive to curtail when it is generating more power than is needed at the time, net of cheaper-to-run renewables.

Simply being low-carbon is not enough: the more urgent climate protection becomes, the more vital "climate-effectiveness" or achieving the greatest greenhouse gas reductions per dollar and per year, becomes.[1465] Carbon reductions sooner are more valuable than carbon reductions decades in the future. Technologies competing with nuclear benefit from faster times to market, and at production scales orders of magnitude higher than that available to new reactors. Incremental innovation, options to pursue multiple technological configurations at once, and economies of scale and learning throughout the supply chain all favor more rapid cost declines in areas competing with nuclear than for nuclear itself.

The innovative pressures are not limited to generation but extend to all attributes affecting the cost and reliability of the service as well— for example, efficient use or demand response, electric-vehicle-to-grid integration, and power storage to address the variable nature of wind and solar generation. Global activity on battery and other power storage approaches and other flexibility options like demand-response are many orders of magnitude larger, spread across multiple markets.

Lazard models estimate that PV plus storage can have load factors of 50 to 70 percent, depending on the region.[1466] Long-term contracts pairing solar and storage are already being struck, such as a 25-year contract by the Los Angeles Board of Water and Power for a price of US$39.62/MWh, and others at similar or slightly lower prices (prices have been trending down).[1467] This was only slightly higher than the average total generating costs in 2021 by single unit reactors (US$37.43/MWh) according to the Nuclear Energy Institute (NEI). Third quartile reactors averaged generating costs of US$34.6/MWh; NEI did not publish data on fourth quartile reactors.[1468] While the full cost of solar with storage is not yet always less expensive than existing reactors in the U.S., it is already competitive in some situations. Increased data and

1464 - David Roberts, "What? The sun isn't always shining?!", Interview with Jesse Jenkins, Princeton University, *Volts*, see https://www.volts.wtf/p/what-the-sun-isnt-always-shining#details, accessed 5 November 2023.

1465 - Mycle Schneider, Antony Froggatt et al., "The World Nuclear Industry Status Report 2019", September 2019, p. 229, see https://www.worldnuclearreport.org/-World-Nuclear-Industry-Status-Report-2019-.html, accessed 1 October 2023, and Amory B. Lovins, "US nuclear power: Status, prospects, and climate implications", *The Electricity Journal*, Vol 35, Issue 4, May 2022, see https://www.sciencedirect.com/science/article/pii/S1040619022000483, accessed 30 October 2023.

1466 - Lazard, "LCOE+", April 2023, op. cit., p.8.

1467 - Sammy Roth, "Los Angeles OKs a deal for record-cheap solar power and battery storage", *Los Angeles Times*, 10 September 2019, see https://www.latimes.com/environment/story/2019-09-10/ladwp-votes-on-eland-solar-contract, accessed 28 August 2023; and John Fitzgerald Weaver, "Los Angeles says 'Yes' to the cheapest solar plus storage in the USA", *PV Magazine*, 10 September 2019, see https://pv-magazine-usa.com/2019/09/10/los-angeles-commission-says-yes-to-cheapest-solar-plus-storage-in-the-usa/, accessed 7 November 2023; and Mycle Schneider, Antony Froggatt et al., "The World Nuclear Industry Status Report 2019", September 2019, see https://www.worldnuclearreport.org/-World-Nuclear-Industry-Status-Report-2019-.html, accessed 1 October 2023.

1468 - NEI, "Nuclear Costs In Context", Nuclear Energy Institute, October 2022, see https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/2022-Nuclear-Costs-in-Context.pdf, accessed 14 November 2023.

infrastructure integration can optimize switching between power sources to control for supply variability in ways impossible in years past; and to link disparate, often distributed, resources into a virtual power plant. Decentralization of power supply, discussed in WNISR2017's review of nuclear finances,[1469] has continued apace, opening a shift from managing supply to meet demand to a system where demand also can be shifted to adjust to power availability.

All of these forces combined are becoming progressively determinative. All are likely to mature over the coming years to propel increasingly formidable competitors to large-scale centralized power generation (including nuclear), and to smaller reactors as well based on current cost trends.

GROWING STATE-OWNERSHIP OF NUCLEAR FUEL CHAIN

State involvement has been a significant part of the nuclear power industry since its inception. David Newbery at the University of Cambridge wrote that "No nuclear power station has ever been constructed without some (and usually extensive) risk mitigation, either by public ownership or under regulatory guarantees."[1470] This involvement seems to be growing, as patterns in new construction and ownership of multiple parts of the nuclear supply chain point to an increasing role of state policy and state funding over market economics. These policies have been implemented instead of, or sometimes on top of, strategies to price carbon. Carbon pricing would also benefit nuclear relative to incumbent fossil competitors, but with greater overall climate and other benefits compared to other support schemes, because it would equally advantage efficient end-use and renewable generation.

The world's nuclear newbuild mainly involves two centrally planned economies—China and Russia. Reactor construction starts have been increasingly concentrated into two buckets: new projects within China and projects in other countries but implemented by Russia. An even more pronounced concentration is evident with reactor manufacturing, as both countries have promoted construction in third countries using their equipment. With the exception of Pakistan, where it has built all six operating units, China has not had widespread success outside of the country yet, though continues to make incremental progress such as having its Hualong One (HPR-1000) design approved by U.K. regulators.[1471] Russian designs have largely dominated reactor construction starts outside China (see other parts of the report).

WNISR analysis of the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS) data shows that over the 2018–2022 period, most reactor construction starts, both by unit count (53 percent) and by nameplate capacity (55 percent), have occurred in China. This is up slightly from roughly 48 percent for both metrics over the longer 2013–2022 period, so Chinese market share has been increasing (see Figure 11). Over the past

1469 - See WNISR2017, "Nuclear Finances – A Tough Market Environment", see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2017-HTML.html#link54, accessed 18 November 2023.

1470 - David Newbery, "The cost of finance and the cost of carbon: a case study of Britain's only PWR", EPRG Working Paper 2013, Cambridge Working Paper in Economics 2047, Energy Policy Research Group, University of Cambridge, May 2020, Updated 9 April 2021, p.3, see https://www.eprg.group.cam.ac.uk/wp-content/uploads/2020/05/2013-Text-REV_Apr21.pdf, accessed 21 July 2023.

1471 - *WNN*, "UK regulators approve China's UK HPR1000 design", *World Nuclear News*, 7 February 2022, see https://www.world-nuclear-news.org/Articles/UK-regulators-approve-China-s%C2%A0UK-HPR1000-design, accessed 21 August 2023.

five years, Russia was second in terms of unit counts (14 percent) and fourth by nameplate capacity (7 percent). Turkey came third with 11 percent of construction starts, or 12 percent by nameplate capacity (second position). Other large reactor construction starts since 2013 have been limited: four each in India and the United States (two of which were cancelled midway); three each in South Korea and the United Arab Emirates; and two each in the U.K. and a handful of other countries, including projects implemented by Russia in newcomer countries Bangladesh, Belarus, and Egypt.

The role of Chinese and Russian equipment can be seen in the reactor designs implemented in new construction starts. Chinese reactors (albeit sometimes derived from designs that were originally Western) made up more than 40 percent of the total over both the past five and the past ten years. The values for Russian reactors were 37 percent for the 2013–2022 period (35 percent of nameplate capacity), rising substantially to 50 percent and 46 percent respectively for the past five years.

During that same period, France was the source of only two reactors and South Korea one. Indeed, two-thirds of reactor construction starts since the beginning of the year 2000 took place either in China and Russia or were implemented by the Russian industry, "where the costs of financing depend on their government's ability to raise money rather than on market interest rates. In the case of these countries—besides China and Russia, in particular Bangladesh, Egypt, India, and Turkey—the government undertakes the projects, electricity demand continues to soar, and public opinion has little chance to interfere with government plans."[1472]

Global uranium enrichment capacity is also heavily controlled by the state-owned enterprises of Russia (46 percent of 2020 capacity) and China (10.5 percent). Even western capacity is mostly government-owned, with involvement by the U.K., France, the Netherlands, and Japan. In total, governments control nearly 90 percent of global enrichment capacity (see Table 17).

A similar pattern exists in uranium mining. The top-ten companies globally contribute about 90 percent of global supply, and more than half of uranium-mine production originates from state-owned mining companies. Russia also owned 38 percent of uranium conversion worldwide in 2020.[1473] Not surprisingly, politics enters production and marketing decisions, as some of the state corporations "prioritise secure supply over market considerations".[1474]

1472 - Mar Rubio-Varas, "Time is money, but sometimes it costs more: an economic history perspective into nuclear projects' pitfalls", Institute for Advanced Research in Business and Economics, Universidad Publica de Navarra, published in *Journal of Mega Infrastructure & Sustainable Development*, Vol. 2, Issue 3, 15 July 2022, p.268, see https://doi.org/10.1080/24724718.2022.2092993, accessed 21 July 2023.

1473 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.28.

1474 - WNA, "World Uranium Mini Production", World Nuclear Association, Updated May 2023, see https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx, accessed 21 July 2023.

Table 17 · State Enterprises Dominate Uranium Enrichment Capacity

Operator	Capacity (thousand SWU/year)				Ownership
	2020		2025	2030	
	Operating Capacity	Estimate State Controlled Capacity (World Market Shares)			
CNNC	6,300	6,300 (10.5%)	11,000	17,000	State owned (China)
Orano	7,500	6,750 (11.2%)	7,500	7,500	90% owned by the French state; 5% owned by Japan Nuclear Fuel Limited; 5% owned by Mitsubishi Heavy Industries (Japan)
Rosatom	27,700	27,700 (46.0%)	26,200	24,800	State owned (Russia)
Urenco	18,600	12,400 (20.6%)	17,300	16,300	Equal shares by: Ultra-Centrifuge Nederland NV (owned by the Government of the Netherlands), Uranit GmbH (owned equally by German energy companies E.ON and RWE) and Enrichment Holdings Ltd (owned by the U.K. Government).
Other*	66	0	375	525	
Total	**60,166**	**53,150 (88.3%)**	**62,375**	**66,125**	

Source: WNA, 2022,[1475] Orano, 2022, company and public websites, compiled by WNISR, 2023

SWU/year: Separative Work Units per year.

* Other includes Argentina, Brazil, India, Pakistan, and Iran.

IN KEY MARKETS, NUCLEAR FINANCE DRIVEN BY GEOPOLITICS, NOT ECONOMICS

These trends highlight government-led nuclear investments of such a scale that industry expert Geoffrey Rothwell concluded in 2022 that "[p]rivately-owned equity companies in the nuclear sector are no longer competitive in international markets" and that "…China and Russia are in the process of putting the West's nuclear industry out of business".[1476] Within China, civil nuclear cooperation is viewed as an integral part of its Belt and Road Initiative, a major foreign policy initiative investing in scores of countries around the world and in alignment with the government's view of China as a rising global power. There are at least 25 countries participating in some type of nuclear reactor cooperation under that initiative. The U.S. National Academy of Sciences notes that there may be a security risk if these engagements lead to weaker Nuclear Cooperation Agreements, particularly with nations hosting their first nuclear infrastructure.[1477]

1475 - WNA, "The Nuclear Fuel Report: Expanded Summary—Global Scenarios for Demand and Supply Availability 2021–2040", World Nuclear Association, April 2022, see https://world-nuclear.org/getmedia/9a2f9405-1135-407a-85c8-480e2365bee7/nuclear-fuel-report-2021-expanded-summary.pdf.aspx; and WNA, "Uranium Enrichment", Updated October 2022, see https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx; both accessed 21 July 2023; also Orano, "Annual Activity Report 2022", 2022, p. 279, see https://cdn.orano.group/orano/docs/default-source/orano-doc/finance/publications-financieres-et-reglementees/2022/orano_annual-activity-report_2022_online.pdf, accessed 14 November 2023.

1476 - Geoffrey Rothwell, "Projected electricity costs in international nuclear power markets", *Energy Policy*, Vol 164, May 2022, pp.3–5, see https://www.sciencedirect.com/science/article/abs/pii/S0301421522001306?via%3Dihub, accessed 21 July 2023.

1477 - NASEM, "Laying the Foundation for New and Advanced Nuclear Reactors in the United States", National Academies of Sciences, Engineering, and Medicine, *The National Academies Press*, 2023, p. 180, see https://doi.org/10.17226/26630, accessed 5 November 2023.

The U.S. Department of Energy is equally blunt: "Russia—a nation that has 'weaponized' its energy supply as an instrument of coercion—dominates nuclear markets."[1478]

China's investments beyond Hinkley Point C in the U.K. are slated to ramp up quickly, with 30 reactor projects abroad by 2030 and an associated investment of more than CNY1 trillion (US$$_{2019}$145 billion).[1479] Helping to propel these deals are China's "advanced nuclear technology, competitive prices and lavish financing," with subsidized sovereign credit covering 80 percent of the cost on projects in Pakistan and 85 percent in Argentina.[1480] Much of the debt on offer to Pakistan carries interest rates of only 1 or 2 percent; the debt on the Argentina project is 4.5 percent.[1481] In comparison, the annualized inflation rate in Pakistan hit a record 38 percent in April 2023.[1482] China also has a history of "debt-for-equity swaps", where defaults on large infrastructure projects are forgiven in return for control over recipient countries' strategic assets, including ports and mines; this approach could be extended to reactor loans, or China could use ongoing construction and maintenance of reactors as a lever in political disagreements.[1483] However, China's latitude for growth may be affected by the inclusion of key providers such as China National Nuclear Group Corporation (CNNC) and China General Nuclear Power Corporation (CGN) on U.S. government blacklists.[1484]

Russia's success in marketing nuclear reactor projects has also relied on low financing rates, as well as favorable terms on fuel supply, and even advance agreements for the spent fuel to be returned to Russia, precluding the need for customers to develop a local disposal capability.[1485] Project data suggests Russian lending rates of 3 to 5 percent, depending on the partner country and date of origination. Russia has taken equity interests in some projects as well.[1486]

These subsidies advance Russian foreign policy objectives by enabling them to play "an important role in the customer country's critical energy infrastructure for the life of the plant," lasting many decades[1487]—a very powerful lock-in effect. Russia's role as a leading nuclear vendor has been harmed by its invasion of Ukraine, however, with cancellation of planned Russian-built nuclear plants in Finland, Jordan, and Slovakia. Rosatom was earlier

1478 - U.S. DOE, "Restoring America's Competitive Nuclear Energy Advantage—A Strategy to Assure U.S. National Security", U.S. Department of Energy, 2020, p.6, see https://www.energy.gov/articles/restoring-americas-competitive-nuclear-energy-advantage, accessed 21 July 2023.

1479 - Lami Kim, "Nuclear Belt and Road and U.S.-South Korea Nuclear Cooperation", Center for Strategic & International Studies, 24 April 2023, see https://www.csis.org/analysis/nuclear-belt-and-road-and-us-south-korea-nuclear-cooperation, accessed 21 July 2023.

1480 - Ibidem.

1481 - Matt Bowen and Alec Apostoaei, "Comparing Government Financing of Reactor Exports: Considerations for US Policy Makers", Center on Global Energy Policy, School of International and Public Affairs, Columbia University, August 2022, p.15 and p.21, see https://www.energypolicy.columbia.edu/wp-content/uploads/2022/08/NuclearFinance-CGEP_Report_111022-1.pdf, accessed 21 July 2023.

1482 - *Al Jazeera*, "Pakistan inflation hits record for second consecutive month", 2 June 2023, see https://www.aljazeera.com/news/2023/6/2/pakistan-inflation-hits-record-for-second-consecutive-month, accessed 21 July 2023.

1483 - Lami Kim, "Nuclear Belt and Road and U.S.-South Korea Nuclear Cooperation", CSIS, April 2023, op. cit.

1484 - Bureau of Industry and Security, "Supplement No. 4 to Part 744 – Entity List", U.S. Department of Commerce, 19 May 2023, see https://www.bis.doc.gov/index.php/documents/regulations-docs/2326-supplement-no-4-to-part-744-entity-list-4/file, accessed 11 September 2023.

1485 - Kacper Szulecki and Indra Overland, "Russian nuclear energy diplomacy and its implications for energy security in the context of the war in Ukraine", *Nature Energy*, 27 February 2023, see https://www.nature.com/articles/s41560-023-01228-5, accessed 31 July 2023.

1486 - Matt Bowen and Alec Apostoaei, "Comparing Government Financing of Reactor Exports: Considerations for US Policy Makers", Columbia University, August 2022, op. cit., p.15.

1487 - NASEM, "Laying the Foundation for New and Advanced Nuclear Reactors in the United States", National Academies of Sciences, Engineering, and Medicine, 2023, op. cit. p.179.

excluded from bids in the Czech Republic following disclosure of Russian involvement in a 2014 explosion at a Czech ammunition depot.[1488]

In contrast, countries like Bangladesh, China, Egypt, and Turkey with existing nuclear construction deals with Russia have largely stayed the course, as has, so far, at least Hungary within the E.U.[1489] While the U.S. sanctions list may be complicating some of these projects (Rusatom Overseas, the state-owned company that implements all nuclear power plant projects outside of Russia on behalf of Rosatom, is on the U.S. Department of State sanction list, for example),[1490] it doesn't seem to have shut them down.[1491] Efforts to move away from Russia have also affected other parts of the fuel chain, with nearly every country looking to diversify supply within days of the invasion.[1492] Implementation can be challenging, though at least five of the six countries operating VVERs in Europe (Bulgaria, Czech Republic, Finland, Hungary, Slovakia, and Ukraine) have signed new supply contracts for fuel fabrication since February 2022 and a concerted E.U.-effort to support the buildup of alternative sources includes all of these countries with the exception of Bulgaria.[1493]

Nuclear-related credit support from other countries does exist, though at a much smaller scale than what is at play with Russia and China. Table 18 summarizes credit support originating from twenty development and export credit providers around the world during 2008–2022, while Figure 56 shows transactions over US$100 million, as compiled by U.S. NGO Oil Change International (OCI) and published in its Public Finance for Energy Database.[1494] Given the challenges of obtaining credit data (and particularly the terms of that support), the database likely provides only a partial picture of what is happening. For example, state bank guarantees to domestic projects, or vendor financing by state-owned vendors, may not show up. U.S. government-subsidized credit to the Vogtle reactors in the U.S. state of Georgia is an example, with US$12 billion in guarantees not captured on the export-focused OCI tabulation.[1495] In addition, reporting may not be consistent across all countries. Reactor projects tabulated by other sources may span a larger time range or reflect commitments that have not all been finalized.

1488 - Kacper Szulecki and Indra Overland, "Russian nuclear energy diplomacy and its implications for energy security in the context of the war in Ukraine", *Nature Energy*, 27 February 2023, op. cit., p. 414.

1489 - Ibidem, pp. 414–415; and Matt Bowen and Alec Apostoaei, "Comparing Government Financing of Reactor Exports: Considerations for US Policy Makers", Columbia University, August 2022, op. cit. p.9; and Andrea Stricler and Anthony Ruggiero, "Ending Global Reliance on Russia's Nuclear Energy Sector", Foundation for the Defense of Democracies, Research Memo, 3 February 2023, see https://www.fdd.org/wp-content/uploads/2023/02/fdd-memo-ending-global-reliance-on-russias-nuclear-energy-sector.pdf, accessed 7 August 2023.

1490 - U.S. Department of State, "Further Curbing Russia's Efforts to Evade Sanctions and Perpetuate its War against Ukraine: Fact Sheet", 12 April 2023, see https://www.state.gov/further-curbing-russias-efforts-to-evade-sanctions-and-perpetuate-its-war-against-ukraine-2/, accessed 18 August 2023.

1491 - Alexandra Prokopenko, "Rosatom: A Difficult Target - Russia's Global Energy Role", Energy Innovation Reform Project, Working Paper No. 1, May 2023, pp. 10-13, see https://www.innovationreform.org/wp-content/uploads/2023/05/EIRP-Russia-Working-Paper-No.1.pdf, accessed 18 August 2023.

1492 - Patricia Cohen, "Why Russia Has Such a s Strong Grip on Europe's Nuclear Power", *The New York Times*, 10 March 2023, see https://www.nytimes.com/2023/03/10/business/economy/russia-nuclear-energy-ukraine.html, accessed 31 July 2023.

1493 - Westinghouse Electric, "Westinghouse-led Project will Secure VVER Fuel Supply in Europe and Ukraine", Press Release, 6 July 2023, see https://info.westinghousenuclear.com/news/westinghouse-led-project-will-secure-vver-fuel-supply-in-europe-and-ukraine, accessed 6 September 2023.

1494 - OCI, "Public Finance for Energy Database", Oil Change International, see https://energyfinance.org/#/, accessed 21 July 2023.

1495 - U.S. Department of Energy, "Vogtle", Undated, see https://www.energy.gov/lpo/vogtle, accessed 11 September 2023.

While ideally information on credit supports should be readily available so taxpayers can see patterns of support across industries and evaluate outcomes, at present the gaps can sometimes be large. This is most evident in lending data for Russian projects. The OCI database tabulates Russian credit support to civilian nuclear projects totaling US$263 million, while Columbia University's Center on Global Energy Policy highlights individual lending and equity commitments orders of magnitude larger, at US$75 *billion*.[1496] The U.S. Department of Energy (DOE) has an even larger number: US$133 billion in foreign orders (not all of which are likely to reach fruition). Most of these probably have some associated sovereign credit support.[1497] The disparity across data sources seems to arise mostly from project finance provided by Rosatom or its subsidiary Atomstroyexport, which are not now captured within the OCI dataset.[1498]

Credit from Chinese institutions to nuclear power equaled US$19 billion according to the OCI database—by far the largest country provider tabulated. Estimates from the Center on Global Energy Policy were US$22 billion, much more closely aligned with the OCI dataset than was the case with the estimates for Russia.[1499]

State investment in reactor projects through subsidized interest rates, non-market lending terms, or equity infusions enable the granting countries to buy market share and create competitive barriers both to non-nuclear substitutes and more market-oriented nuclear power competitors. OECD countries, for example, participate in the 1978 "Arrangement on Officially Supported Export Credits", which limits subsidies on credit support. Specifically, the arrangement requires interest rates tied to national Treasury rates using the Commercial Interest Reference Rates (CIRR); requires the use of risk premia for default risk; caps directed trade at no more than 85 percent imported content, and local content at no more than 30 percent (prior to 2021); and caps repayment periods at 18 years for nuclear projects (though this period is longer than what is allowed for other types of borrowers). Some flexibility in the schedule of repayments is allowed, but only if weighted-average loan duration does not exceed nine years and the maximum repayment term is 15 years.[1500] This last provision prevents backloading loan payments or interest to the very end of the lending period, a practice that increases the net present value of the subsidy.

The Export-Import Bank of the United States (EXIM Bank) financed "most of the world's nuclear projects sold internationally from 1965 to 1985".[1501] Repayment periods for nuclear were twice as long as for other EXIM Bank projects, with grace periods of up to nine years. In recent decades, this funding for reactor projects stopped. However, the OCI data highlight US$2.3 billion in credit support for U.S. equipment and services to foreign nuclear projects.

1496 - Matt Bowen and Alec Apostoaei, "Comparing Government Financing of Reactor Exports: Considerations for US Policy Makers", Columbia University, August 2022, op. cit. p.15.

1497 - U.S.DOE, "Restoring America's Competitive Nuclear Energy Advantage—A Strategy to Assure U.S. National Security", op. cit. p.6.

1498 - Claire O'Manique, "Oil Change International", Earth Track, personal email to Doug Koplow, 7 July 2023.

1499 - Matt Bowen and Alec Apostoaei, "Comparing Government Financing of Reactor Exports: Considerations for US Policy Makers", Columbia University, August 2022, op. cit., p.20–21.

1500 - Matt Bowen and Alec Apostoaei, "Comparing Government Financing of Reactor Exports: Considerations for US Policy Makers", Columbia University, August 2022, op. cit. p.9.; and David Drysdale, "OECD Financing Rules for Nuclear Power Projects", Head of the Export Credit Division, OECD, presented at the International Framework for Nuclear Energy Cooperation, 2016 see https://www.ifnec.org/ifnec/jcms/g_7706/d-drysdale-oecd-financing-rules-for-nuclear-power-projects?details=true, accessed 21 July 2023.

1501 - Mar Rubio-Varas, "Time is money, but sometimes it costs more: an economic history perspective into nuclear projects' pitfalls", *Journal of Mega Infrastructure & Sustainable Development*, July 2022, op. cit., p.265.

Their dataset also captures material credit support to nuclear exports by the European Investment Bank (EBRD) towards France, India, Italy, Japan, and South Korea.

Industry and government officials have been working to increase the role of these institutions as a source of subsidized credit to the nuclear energy industry. Over the past three years, large nuclear funding packages have started to inch forward. The U.S. has issued letters of interest for US$4 billion in financing for SMRs in Poland (US$3 billion from EXIM Bank and US$1 billion from Development Finance Corporation),[1502] the same for SMRs in Romania,[1503] and supposed EXIM Bank support for 85 percent of the cost of the first two reactors (estimated cost US$10 billion) of a multi-reactor project in Ukraine.[1504] (See Poland Focus and section on Romania.)

Legislation to move international development banks into the area of nuclear finance has also been introduced for the past few years in the United States. If passed, the International Nuclear Energy Financing Act would

> require the United States Executive Director at the World Bank to advocate and vote for financial assistance for nuclear energy. The bill would also permit U.S. representatives at other international financial institutions – including regional development banks for Asia, Africa, Europe, and Latin America – to push for nuclear projects. Taken together, the multilateral development banks can commit over [US]$100 billion in annual financing.[1505]

This would be a substantial change as major development banks like the World Bank, the Asian Development Bank (ADB) or the European Bank for Reconstruction and Development (EBRD) have never financed nuclear newbuild projects, considering them too risky. All these institutions are now under massive political pressure to reverse this policy.

1502 - Marek Strzelecki, "Polish small reactors project may get up to $4 bln in U.S. financing", *Reuters*, 17 April 2023, see https://www.reuters.com/business/sustainable-business/polish-small-reactors-project-may-get-up-4-bln-us-financing-2023-04-17/, accessed 21 July 2023; and EXIM, "Export-Import Bank of the United States Issues a $3B Letter of Interest for U.S. Nuclear Exports to Poland", Press Release, 17 April 2023, see https://www.exim.gov/news/export-import-bank-united-states-issues-3b-letter-interest-for-nuclear-exports-poland, accessed 17 November 2023.

1503 - The White House, "The United States and Multinational Public-Private Partners Look to Provide Up To $275 Million to Advance the Romania Small Modular Reactor Project; United States Issues Letters of Interest for Up To $4 Billion in Project Financing", Press Release, 20 May 2023, see https://www.state.gov/the-united-states-and-multinational-public-private-partners-look-to-provide-up-to-275-million-to-advance-the-romania-small-modular-reactor-project-united-states-issues-letters-of-interest-for-up-to/, accessed 17 November 2023.

1504 - Kostiantyn Krynytskyi and Olexi Pasyuk "What is wrong with EXIM's plan to pay for Westinghouse reactors in Ukraine?", Briefing, Energy Department Center for Environmental Initiatives Ecoaction, CEE Bankwatch Network, 20 March 2023, see https://bankwatch.org/wp-content/uploads/2023/03/Exim-Westinghouse-in-Ukraine-Briefing-March-2023.pdf, accessed 21 July 2023.

1505 - Patrick McHenry, "McHenry, Hill Reintroduce Bill to Finance Nuclear Energy at the World Bank and Other International Lenders", Press Release, Chairman of House Financial Services Committee, 7 February 2023, see https://financialservices.house.gov/news/documentsingle.aspx?DocumentID=408560, accessed 21 July 2023.

Table 18 · Patterns in Sovereign Credit Support to Nuclear Power, 2008–2022

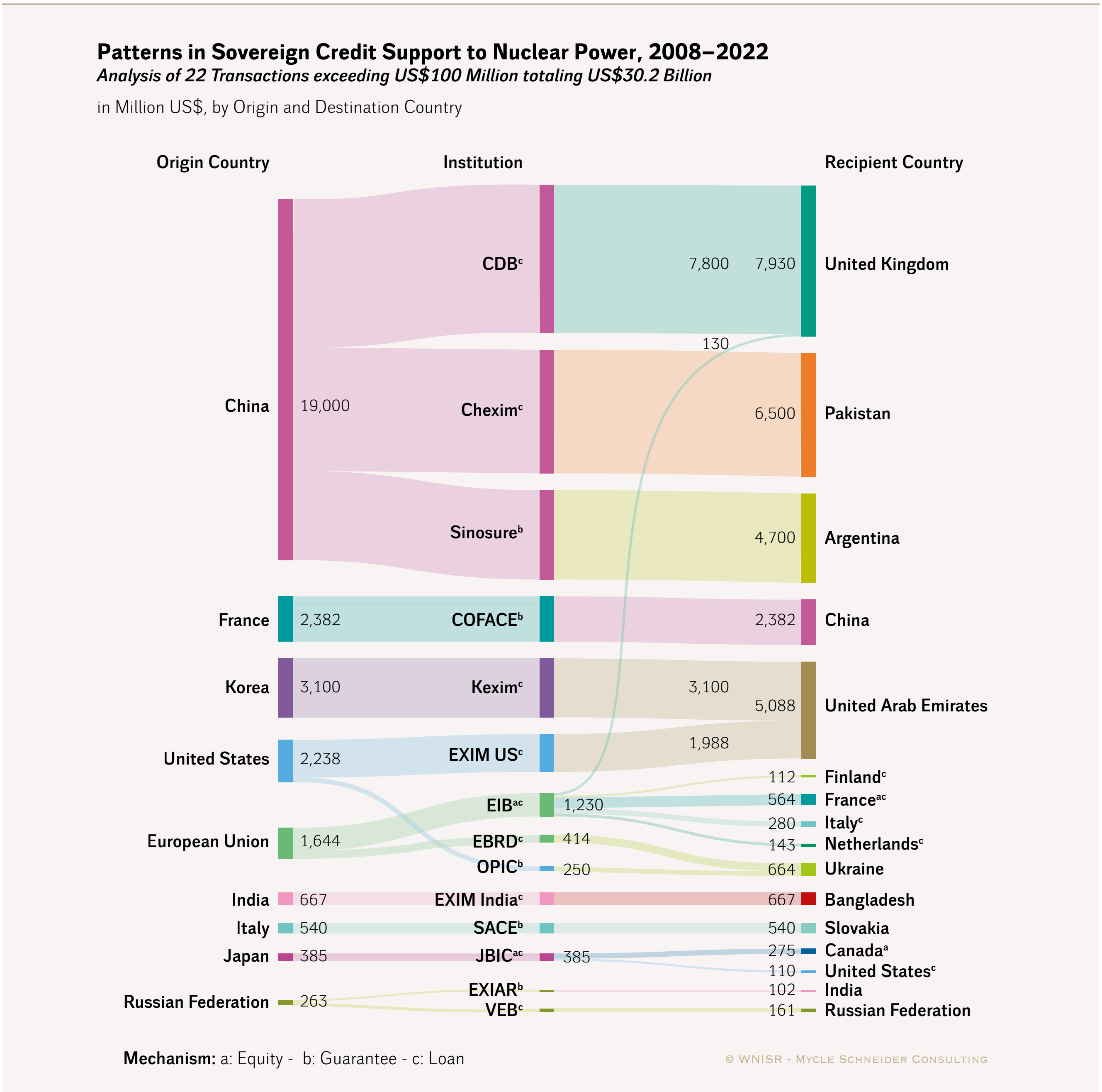
	Patterns in Sovereign Credit Support to Nuclear Power, 2008–2022 Analysis of 43 Transactions totaling 30.7 Billion US$ (in Million US$)						
Origin Country	**Institution***	**Recipient Country**	**Project**	**Funding Mechanism**			
					Equity	**Guarantee**	**Loan**
Australia	EFIC	U.K.	Consulting on Nuclear Waste Management			0.2	
Brazil	BNDES	Brazil	Eletronuclear				21.5
Canada	EDC	Canada	Cameco Corporation				39.3
		South Korea	Tyne Engineering Corporation				0.7
	SDTC	Canada	Demonstration of Fusion Energy Technology	9.5			
China	CDB	U.K.	Hinkley Point C Nuclear Project				7,800.0
	Chexim	Pakistan	Karachi Nuclear Power Complex (K-2/K-3)				6,500.0
	Sinosure	Argentina	Argentina Nuclear Plant			4,700.00	
E.U.	EBRD	Ukraine	Nuclear Power Plant Safety Upgrade Program				414.3
	EIB	Finland	TVO Safety Improvements				112.2
		France	AREVA Uranium Enrichment Facility - A		286.0		278.0
		Italy	ENEA - Divertor Tokamak Test Facility				280.8
		Netherlands	Urenco Uranium Enrichment Facility II				242.0
		Slovakia	SE Safety Improvement				68.3
		U.K.	Urenco Uranium Enrichment Facility II and II C				227.0
France	COFACE	China	Taishan Nuclear Power Plant			2,448.5	
India	EXIM India	Bangladesh	Bangladesh India Exim Bank LoC 2017 (Rooppur nuclear power plant)				666.7
Italy	SACE	Slovakia	Mochovce 3&4 Project			540.00	
Japan	JBIC	Canada	Joint investment in Uranium One Inc. (U1) (UUU.TO)		274.6		
		U.S.	Equity Participation in NuScale Power, LLC				110.0
South Korea	Kexim	U.A.E.	Barakah Nuclear Power Plant (5600 MW)				3,100.0
		Jordan	Research-and-Training Reactor Construction Project				12.8
Russia**	EXIAR	India	Kudankulam Nuclear Power Plant			102.4	
	VEB	Russian Federation	Multipurpose Research Reactor				160.5
U.K.	UKEF	China	Sale of pumps and spares to Chinese Nuclear Energy Industry Corp			9.1	
		Switzerland	Pumps (Arcade UK Ltd)			0.1	
U.S.	EXIM US	Mexico	Nuclear Power			64.5	
		UAE	Abu Dhabi Nuclear Plant				1,988.2
		U.S.	Consult Services for Nuclear Power Station			1.1	
	OPIC	Ukraine	Energoatom Central Spent Nuclear Fuel Storage Facility			250.00	
				10	561	8,116	22,053
				30.7 Billion			

Source: Oil Change International's Public Finance for Energy Database, May 2023

*Acronyms
BNDES: Brazilian Development Bank
CDB: China Development Bank
Chexim: Export-Import Bank of China
COFACE: Compagnie Française d'Assurance pour le Commerce Extérieur
EBRD: European Bank for Reconstruction and Development
EDC: Export Development Canada
EFIC: Export Finance Australia
EIB: European Investment Bank
ENEA: Italian National Agency for New Technologies, Energy and Sustainable Economic Development
EXIAR: Export Insurance Agency of Russia
EXIM India: Export-Import Bank of India
EXIM US: Export-Import Bank of the United States
JBIC: Japan Bank for International Co-operation
Kexim: Export-Import Bank of Korea
OPIC: Overseas Private Investment Corporation
SACE: Servizi Assicurativi del Commercio Estero
SDTC: Sustainable Development Technology Canada
SE: Slovenské elektrárne
Sinosure: China Export and Credit Insurance Corporation
TVO: Teollisuuden Voima Oyj
UKEF: UK Export Finance
VEB: Russian Development Bank

**Lending data for the Russian Federation is clearly missing many important project lenders, with the result that the US$263 is not to be considered representative for Russian nuclear lending activities.

Figure 56 · Patterns in Sovereign Credit Support to Nuclear Power, 2008–2022



Source: Oil Change International's Public Finance for Energy Database, May 2023

STATE INTERVENTIONS PLAY A LARGE ROLE EVEN OUTSIDE OF CHINA AND RUSSIA

Even outside of China and Russia, the role of the state is large and has been growing. The IEA notes that "[d]ue to their size and complexity, nuclear projects have historically relied upon some form of state ownership or regulated monopoly structure in order to guarantee revenues and reduce risk to [private] investors".[1506] The largest reactor operator in the world, Électricité de France (EDF), with 65 units (56 in France and 9 in the U.K.) and nearly 17 percent of global nuclear capacity in operation or construction, was fully renationalized in 2022–2023 due to financial challenges.[1507] A review of PRIS data on reactor operators by WNISR indicates majority or full state ownership in other countries including Bulgaria, Japan, South Korea, UAE, and Ukraine, as well as the Province of Ontario in Canada; and for the Tennessee Valley Authority reactors in the U.S. Operators of more than 45 percent of global nuclear capacity are state-owned. State ownership may sometimes arise later in a project, such as when they run into problems. The U.K. government, for example, recently invested more than US$800 million into the Sizewell C Project as part of a buyout of the Chinese state-owned partner,[1508] and is expected to provide much or most of the project's total equity capital if private investors remain reluctant to invest. State ownership often results in a wide array of subsidies to credit, risk management, resource inputs, and tax liabilities, many of which are difficult to see or quantify. These can exist even when a state-owned company is listed on the public stock market. Further, state involvement can be significant even without direct ownership: for example, India's nuclear program was historically "orchestrated exclusively by the government and displayed a rigid adherence to centralized planning."[1509]

Privately-owned reactors, such as dominate in the U.S., benefit from an array of supports as well. Frequently, these aim to reduce construction and market risks, and with them the cost of capital to owners. Mechanisms of support often include government-subsidized loans and loan guarantees to help fund construction; and interest-free customer financing to pay interest costs on new reactor construction via bill surcharges, such as construction work in progress (CWIP) schemes in the U.S. (see United States Focus) and the emerging Regulated Asset Base (RAB) model in the U.K. (see United Kingdom Focus). Market risks may be shifted off investors and owners using above market payments for power (feed-in subsidies or zero emission credits) or guaranteed price floors such as a Contract for Difference. Because construction delays and cost overruns have been common on reactor projects, market conditions and the pricing of electricity produced may have greatly changed between when a build-decision is made and the day the reactor finally comes online. Government subsidies to hedge these risks can be very valuable to the nuclear sector, though they disadvantage other energy service options that have shorter delivery periods and more predictable development costs.

1506 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.24.

1507 - Ministère de l'Économie, des Finances et de la Souveraineté Industrielle et Numérique, "L'État redevient l'actionnaire unique d'EDF", Press Release No. 919 (in French), French Government, 8 June 2023.

1508 - Peter Reina, "UK Invests $815M in Sizewell C Nuclear Project in China Buyout", *Engineering News Record*, 30 November 2022, see https://www.enr.com/articles/55470-uk-invests-815m-in-sizewell-c-nuclear-project-in-china-buyout, accessed 22 August 2023.

1509 - Benjamin K. Sovacool and Scott Victor Valentine, "The socio-political economy of nuclear energy in China and India", Lee Kuan Yew School of Public Policy, National University of Singapore, and Graduate School of Public Policy, University of Tokyo, published in *Energy*, Vol. 35, Issue 9, 20 June 2010, p.3807, see https://www.sciencedirect.com/science/article/abs/pii/S0360544210003038, accessed 21 July 2023.

Government interventions are not limited only to power generation. In nearly all countries, the costs and technical challenges of handling high-level nuclear waste have been shifted partly or wholly to the state. Required liability coverage for accident risks is covered to some degree by national statutes or international treaties, but such coverage is always well below damages that would be incurred in a significant accident. Accruals to cover asset retirement obligations, primarily plant decommissioning and associated site remediation, vary in scale and form by country, with many shifting some or all the cost of funding plant closure to taxpayers. Further, as with accident risks, taxpayers remain the residual liability holders, should accumulated funds by plant owners prove insufficient.

Many renewable technologies also benefit from government subsidies. These programs are not as old as those supporting nuclear power. Further, they have historically been structured to phase out as the technologies mature, either based on statutory eligibility or achieved by market forces such as through bidding rounds for Renewable Portfolio Standards. In many regions of the world, renewable energy projects—especially wind and solar PV—are increasingly planned and implemented with few or no subsidies. In contrast, many significant supports to nuclear are permanent and some have been in place since the 1950s. No comprehensive independent analysis compares nuclear with competitors' subsidies for the world, and many of the core supports to nuclear come through state ownership and shifting of long-term risks, which are the least well-quantified support types globally. Further, few (if any) individual countries have such analyses recent enough to be meaningful. In combination, this leaves nuclear advocates free to claim that their subsidies are small, or at least less than subsidies to renewable sources, when this may not actually be the case.

OPERATING REACTORS FACE CONTINUED COMPETITIVE PRESSURE, RECEIVE STATE SUPPORT

For decades, proponents have characterized nuclear power as "expensive to build but relatively cheap to run".[1510] The characteristics driving this claim are low operating costs in comparison to other power sources, a long operating life for reactors, and high load factors that enable the investment costs of nuclear power plants to be spread over many kWh, thereby reducing the fixed costs per unit of energy produced. Indeed, data on the U.S. fleet collected by the Nuclear Energy Institute, a trade association, suggests significant real cost declines in fuel, operating, and capital costs since 2012.[1511] U.S. load factors have also remained high; those outside of the U.S. are not as high, but still robust in comparison to most competing forms of electricity generation.

Despite this long-held view, headwinds are affecting even the operating reactors in many countries. In recent years, unplanned outages have cut into output, and aging reactors or unexpected problems have sharply driven up plant repair and reinvestment costs, particularly in France and Japan. Nuclear plant performance has also suffered from climate-related impacts, such as cooling water availability, heat sink capacity, and storm events. Climate-

1510 - WNA, "Economics of Nuclear Power", World Nuclear Association, Updated August 2022, see https://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx, accessed 3 July 2023.

1511 - NEI, "Nuclear Costs in Context", Nuclear Energy Institute, October 2022, p.3, see https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/2022-Nuclear-Costs-in-Context.pdf, accessed 21 July 2023.

related disruptions of nuclear generation have increased eight-fold over the past 30 years, according to a study published in *Nature Energy*.[1512]

More systemically, growing market pressure from less expensive competitors pose a significant and long-lasting threat. This has arisen primarily from low-cost natural gas, but increasingly wind and solar represent serious competitive risks for nuclear as well, especially during certain periods of the year or times of day. The combined result has been a reduction in wholesale prices, and with them declining revenues to nuclear power plants that have historically competed by running at full capacity all the time. In Finland, for example, the Olkiluoto-3 nuclear reactor commenced commercial operation in mid-April 2023. Yet, a month later, surging renewables production and negative wholesale power prices forced curtailment of nuclear generation.[1513] Similar cuts have been made at Spanish reactors.[1514]

In the short term, these pressures vary: for example, the Russian invasion of Ukraine drove European power prices up sharply, and increased exports of LNG from the U.S. to replace disrupted European supplies did the same in the U.S. However, over longer market cycles, competitive pressures have resulted in even operating reactors—where all or most of the original invested capital has already been paid off—closing or threatening to close. In the U.S., for example, 13 reactors officially closed between 2013 and 2022 (including three reactors that had ceased electricity production in 2009 and 2012; see Figure 52). The cost pressures are evident primarily in competitive power markets; in regulated markets, higher costs are simply passed through to customers.

Note that in other sectors of the economy, innumerable facilities have shut down temporarily or permanently when changing market conditions have rendered their products too expensive or no longer desired by consumers. Permanent shutdowns happen routinely, and rarely is this because the facility is no longer physically able to produce its product. Those closures are not viewed as "premature" but rather as the normal functioning of market forces, retiring obsolete assets to make way for competitive new ones.

Nuclear plant closures have been viewed entirely differently. Arguing that plant closures would drive up carbon emissions and that their product, labelled "low-carbon, reliable power", was not being properly valued by the market, the industry has tagged the closures as premature, and has lobbied for—and increasingly often successfully obtained—subsidies to remain in operation. Below are some examples of operating conditions in key countries and associated state subsidies to keep the sector going. Additional information can be found in the country-specific chapters with a detailed assessment in United States Focus.

United States (state level). Threats of reactor closures led to implementation of state-level per-MWh taxpayer-financed subsidies for 19 U.S. reactors, with payments lasting from five to 12 years depending on the state and the specific program. Affected states now include New York, Illinois, New Jersey, and Connecticut. The Connecticut program also incorporates

1512 - Ali Ahmad, "Increase in frequency of nuclear power outages due to changing climate", Harvard University, published in *Nature Energy*, July 2021, see https://doi.org/10.1038/s41560-021-00849-y, accessed 14 September 2023.

1513 - *YLE*, "Finnish nuclear plant throttles production as electricity price plunges", 17 May 2023, see https://yle.fi/a/74-20032375, accessed 24 November 2023.

1514 - Pablo Bronte, "España modula sus reactores para ayudar a las renovables", *Montel*, 8 September 2023 (in Spanish), see https://www.montelnews.com/es/news/1521095/espaa-modula-sus-reactores-para-ayudar-a-las-renovables, accessed 11 September 2023.

one reactor in New Hampshire.[1515] Total subsidies through these programs are estimated to exceed US$15 billion by 2030 and increase further should the programs be extended.[1516] A similar program in Ohio was ultimately rescinded upon discovery that US$60 million in bribes had been directed to politicians in return for passage of the US$1 billion subsidy to nuclear reactors. That was the largest public bribery case in Ohio's history[1517], and it continues to reverberate.

United States (federal level). Production Tax Credits (PTC) have historically been implemented to subsidize the deployment of *new* capital infrastructure in the power sector, with the idea that the capital investment was the main hurdle in developing new capacity that could then compete on its own. More recently, policies have extended PTCs beyond the eligibility time-period set in the original statutes, resulting in a structure similar to operating subsidies. The Zero-Emission Nuclear Production Credit extended an earlier PTC for new plants to include *existing* nuclear plants as well. It offers a maximum of US$15/MWh for plants operating from 2024 to 2032. These may possibly be combined with large subsidies also being offered for hydrogen produced from "clean" (low carbon) energy. Flexibility to sell such subsidies to parties with higher tax liability, or in some cases to have their value paid directly to the operator by the Treasury, has increased the subsidy value to investors and plant owners.

The Civil Nuclear Credit (CNC) program funded a national pool of US$6 billion in subsidies to keep economically distressed reactors from closing. The structure is more efficient than the flat per-kWh payments many states have implemented, as reactors must bid the minimum subsidy they claim to need to continue operating, and multiple bids are competed against each other. There is an initial five-year program window with an extension possible. The Diablo Canyon plant in California was awarded US$1.1 billion to remain in production in the initial round (2022).[1518] The CNC application requires disclosure of other supports, though receipt of subsidies from other programs is not disqualifying. Further, restrictions on use of the CNC in regulated markets have been relaxed. The provision is now also open to reactors that closed after 15 November 2021.[1519] This second change facilitates eligibility for restarting the Palisades reactor in Michigan, despite safety issues of concern. The reactor appears to have applied for loan guarantees of US$1 billion under a different federal program that owners viewed as a "better fit".[1520]

1515 - Tim Judson, "Phase Out, Don't Bail Out - Nuclear Subsidies: A Dead End for Maryland's Climate Future", presentation to the Baltimore Energy Justice Forum, 29 February 2020; and Muhammad Maladoh Bah, "State and federal nuclear support schemes in dynamic electricity market conditions: Insights from NYISO and PJM", University of Basel, as published in *Energy Policy*, Vol. 182, November 2023, see https://doi.org/10.1016/j.enpol.2023.113764, accessed 28 August 2023.

1516 - Tim Judson, "Phase Out, Don't Bail Out - Nuclear Subsidies: A Dead End for Maryland's Climate Future", presentation to the Baltimore Energy Justice Forum, 29 February 2020, op. cit.; and Tim Judson, Email to Doug Koplow, Earth Track, Inc., 26 June 2023.

1517 - Michael Wines, "A $60 Million Bribe. A $1.3 Billion Bailout. A 20-Year Prison Sentence", *The New York Times*, 29 June 2023, see https://www.nytimes.com/2023/06/29/us/ohio-speaker-bribery.html, accessed 21 July 2023.

1518 - Grid Deployment Office, "Civil Nuclear Credit Program", U.S. Department of Energy, 2023; and MarkHolt and Phillip Brown, "U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns", CRS Report R46820, Congressional Research Service, Updated 7 February 2022, see https://crsreports.congress.gov/product/pdf/R/R46820/6, accessed 21 July 2023.

1519 - Muhammad Maladoh Bah, "State and federal nuclear support schemes in dynamic electricity market conditions: Insights from NYISO and PJM", *Energy Policy*, op. cit.; and Timothy Gardner, "Biden admin offers $1.2 bln for distressed, shut nuclear plants", *Reuters*, 3 March 2023, see https://www.reuters.com/world/us/biden-admin-offers-12-bln-distressed-shut-nuclear-plants-2023-03-02/, accessed 6 November 2023.

1520 - John Flesher, "Company seeks first-time restart of shuttered nuclear plant", *The Associated Press*, 6 April 2023, see https://apnews.com/article/palisades-nuclear-power-biden-whitmer-55019ca6d17c2b1965cae0de2f3a6235, accessed 6 November 2023.

France. The French reactor fleet needed to stabilize operations following widespread and unplanned corrosion problems that—together with aging issues, climate-induced operating restrictions, strikes, and more—resulted in roughly half of the country's 56 reactors being taken offline for extended periods (see France Focus for details). Maintenance costs also surged. Revenue losses from reduced production were compounded by two other factors. First, price caps were implemented to buffer damage to consumers following energy market dislocations from the Russian invasion of Ukraine. Second, a 2010 agreement—called ARENH (Accès Régulé à l'Électricité Nucléaire Historique) implemented with the E.U. to address concerns about EDF becoming a monopoly supplier—mandated EDF to sell 100 TWh, then about one-fourth of its production, to competitors at a fixed price. In 2023, this portion of production earned EDF revenues only about 1/10th of its market value.[1521] Total losses for 2022 were €17.9 billion (US$$_{2022}$18.8 billion), contributing significantly to rising total net debt of €64.5 billion (US$$_{2022}$67.9 billion).[1522] Facing worsening fundamentals, the French government renationalized EDF and announced a restructuring of its nuclear activities in June 2023.[1523] Government ownership will bring down borrowing costs because rates will follow the sovereign, not the business. Large cash infusions from the government are expected, supporting both continued operation of existing reactors and new construction projects.

Belgium. A framework agreement between government and utility Engie to restart and extend the operations of two reactors was finalized in June 2023. While not fully public yet, the deal includes a price floor using a Contract-for-Difference approach and caps the waste liability for all Engie reactors in Belgium (not just the ones being restarted/lifetime extended). "As a result of the transfer of all nuclear waste liabilities to the Belgian government, Engie will no longer be exposed to the evolution of future costs related to the management of waste",[1524] where "evolution" presumably means "large increases in unpredictable costs".

Japan. Since the Fukushima disaster began in 2011, Japan has spent approximately US$77.5 billion (¥$_{2023}$10,817 billion) in compensation and remediation costs as of June 2023, according to TEPCO. Most of this has been funded by the national government, thus the taxpayer.[1525] Operators have applied for the restart of 25 reactors. As of July 2023, seventeen had received regulatory approval, but only ten had resumed operation.[1526] To expedite the restart of reactors shuttered since 3/11 by required safety and security upgrades, the Japanese government is considering subsidies that would guarantee income to winning bidders for the subsequent 20 years. This would be an extension of the "long-term decarbonized power supply auction" slated to begin in early 2024. The budget for this program has not been mentioned

1521 - Silvia Aloisi and Forrest Crellin, "Explainer: Why a French plan to take full control of EDF is no cure-all", *Reuters*, 13 July 2022, see https://www.reuters.com/business/energy/why-french-plan-take-full-control-edf-is-no-cure-all-2022-07-07/, accessed 21 July 2023.

1522 - EDF, "2022 Annual Results: Significant Downturn in Results in a Context of French Power Output Shortfall and High Market Prices", Press Release, 17 February 2023, see https://www.edf.fr/sites/groupe/files/2023-02/annual-results-2022-pr-en-2023-02-17.pdf, accessed 7 August 2023.

1523 - Elizabeth Pineau, Benjamin Mallet, Josephine Mason and Leigh Thomas "Exclusive: EDF CEO tells managers nuclear business to be reorganized", *Reuters*, 29 June 2023, see https://www.reuters.com/business/energy/edf-ceo-tells-managers-nuclear-business-be-reorganised-2023-06-29/, accessed 21 July 2023.

1524 - *WNN*, "Agreement reached for extended operation of Belgian reactors", *World Nuclear News*, 29 June 2023, see https://www.world-nuclear-news.org/Articles/Agreement-reached-for-extended-operation-of-Belgia, accessed 21 July 2023.

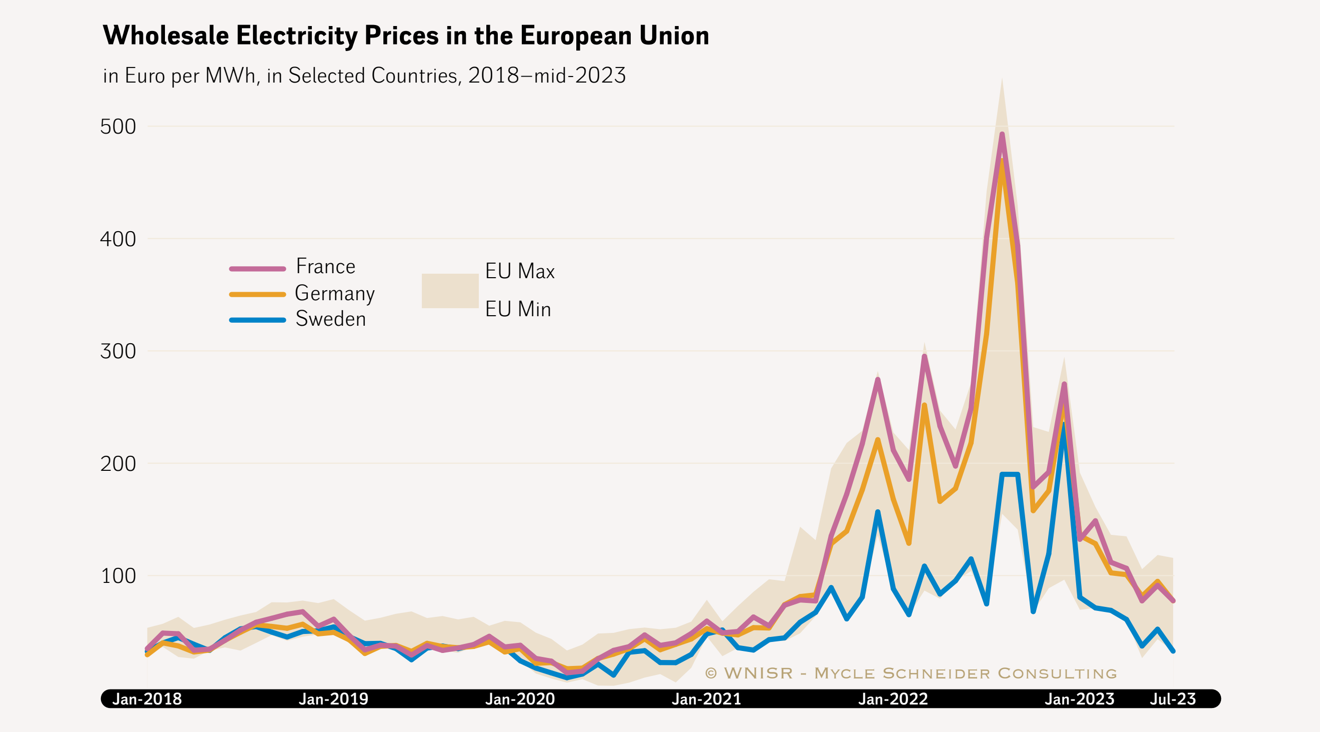
1525 - TEPCO, "Baisho Kin no Oshiharai Jokyo" ["Current status of Compensation paid so far"], Tokyo Electric Power Co Holdings, 23 June 2023, see https://www.tepco.co.jp/fukushima_hq/compensation/images/jisseki01-j.pdf, accessed 26 June 2023.

1526 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 10 July 2023, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2023/07/jp-npps-operation20230710_en.pdf, accessed 16 November 2023.

in press coverage about the plan.[1527] Earmarking funds for nuclear operations would reduce funding available for non-nuclear bidders.

European Union. Price caps to buffer customers from sharply rising power and fuel prices following the Russian invasion of Ukraine were adopted across the E.U. They have been quite costly. As of June 2023, the subsidy had hit €758 billion (US$814 billion) across 29 European countries.[1528] Value-Added Tax (VAT)-cuts and price caps played a significant role.[1529] The subsidies allowed consumers to continue to purchase energy products despite the scarcity-induced price surges and reduced or waived taxes and operating fees on energy providers, including power stations. Prices continued to rise through most of 2022 but have started to stabilize in 2023, in part because of the E.U. market interventions.[1530] It is noteworthy that wholesale prices during the high-price period between the second quarter 2022 and the first quarter 2023 were consistently higher in France than in Germany (see Figure 57).

Figure 57 • Wholesale Electricity Prices in the European Union, 2018–mid-2023



Sources: ENTSO-e and EMBER, 2023[1531]

1527 - Stephen Stapczynski and Shoko Oda, "Japan Considers Subsidies to Help Restart Idled Nuclear Plants", *BNN Bloomberg*, 26 July 2023, see https://www.bnnbloomberg.ca/japan-considers-subsidies-to-help-restart-idled-nuclear-plants-1.1950604; and *NEI Magazine*, "Japan considers subsidy scheme to restart idled reactors after Fukshima, 28 July 2023, see https://www.neimagazine.com/news/newsjapan-considers-subsidy-scheme-to-restart-idled-reactors-after-fukushima-11033995; both accessed 22 August 2023.

1528 - Bruegel, "National fiscal policy responses to the energy crisis", 26 June 2023, see https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices, accessed 7 August 2023.

1529 - Charlotte Elton, "The spending earmarked by the countries on the energy crisis is now in the same league as the EU's 750-billion-euro COVID-19 recovery fund", *Euronews.green, 13 February 2023, see* https://www.euronews.com/green/2023/02/13/energy-crisis-europes-spend-to-shield-consumers-nears-800-billion-where-is-the-money-going, accessed 21 July 2023.

1530 - Eurostat, "Electricity & gas hit record prices in 2022", Statistical Office of the European Union, 26 April 2023, see https://ec.europa.eu/eurostat/web/products-eurostat-news/w/DDN-20230426-2, accessed 21 July 2023.

1531 - EMBER, "European power price tracker", Updated July 2023, see https://ember-climate.org/data/data-tools/europe-power-prices/, accessed 21 July 2023.

ECONOMICS OF NEW REACTORS IN THE CONTEXT OF GOVERNMENT SUPPORT

The prevalence of state interventions throughout the nuclear fuel chain makes evaluating the core market economics of the power source more challenging. Engineering studies are often used, including both overnight capital costs (OCC) and levelized cost of energy (LCOE) assessments. OCC present the costs of a new nuclear plant as if it were built "overnight". The approach simulates delivered costs were there to be zero cost of capital and excludes such factors as operating costs, grid connections, and site improvements. LCOE assessments incorporate the timing of plant construction costs and revenues, as well as the cost of capital, plant operation, and capacity utilization levels, but generally exclude potential technology-specific system costs.

Overnight Capital Costs Vary Significantly Across Countries—Reasons Not Always Clear

Evaluations of overnight capital costs are simpler to perform than LCOEs. The approach can be useful in highlighting differences across countries and drilling down to seek the cause. For example, OECD's Nuclear Energy Agency data co-published with the International Energy Agency illustrates overnight costs that vary by more than a factor of three across countries.

Table 19 · NEA/IEA Nuclear Overnight Cost and Total Investment Cost Estimates (in US$2018)

Country	Technology	Net capacity (MWe)	Overnight costs (US$/kWe)	Investment costs (US$/kWe)		
				3%	7%	10%
France	EPR	1 650	4 013	4 459	5 132	5 705
Japan	ALWR	1 152	3 963	4 402	5 068	5 633
South Korea	ALWR	1 377	2 157	2 396	2 759	3 066
Russia	VVER	1 122	2 271	2 523	2 904	3 228
Slovakia	Other nuclear	1 004	6 920	7 688	8 850	9 837
United States	LWR	1 100	4 250	4 721	5 435	6 041
China	LWR	950	2 500	2 777	3 197	3 554
India	LWR	950	2 778	3 086	3 552	3 949

Sources: IEA/NEA, 2020[1532]

A more expansive review of cost data from the Workgroup for Infrastructure Policy (WIP) at the Technical University of Berlin (TU Berlin) and the German Institute for Economic Research (DIW Berlin) included estimates for 88 reactors. These were culled from the academic press, university and trade association studies, engineering reports, national energy ministries and research laboratories, and include both projections and actual costs. Actual costs tended to be much higher than projected. Despite including the more optimistic cost projections as well,

1532 - IEA and OECD/NEA, "Projected Costs of Generating Electricity—2020 Edition", International Energy Agency, and Nuclear Energy Agency, Organisation for Economic Co-operation and Development, 2020, pp.41 and 49, see https://iea.blob.core.windows.net/assets/ae17da3d-e8a5-4163-a3ec-2e6fb0b5677d/Projected-Costs-of-Generating-Electricity-2020.pdf, accessed 21 July 2023.

Table 19 shows a higher *median* OCC than the values reported within the IEA/NEA data by every country other than Slovakia.[1533] WIP and DIW also show Small Modular Reactor (SMR) costs significantly higher than for Light Water Reactors (LWRs), highlighting the fact that a lower total build cost per smaller reactor will not help the competitive growth of this emerging sector if the cost per installed capacity unit remains significantly above LWR costs.[1534] For SMRs, the discrepancy between to-be expected costs and manufacturer projections is exceptionally high.[1535]

Table 20 · DIW/WIP Nuclear Overnight Cost Estimates

	Overnight construction costs by reactor type in US$ per kW			
Measure	**All types**	**Standard LWR**	**SMR**	**Non-LWR**
Mean	6,279.41	6,008.85	7,774.17	5,030.55
Median	5,353.64	5,515.00	6,270.29	5,311.51
25%-Quantile	4,319.80	4,328.00	4,472.66	4,453.58
75%-Quantile	7,146.76	6,965.92	7,978.75	5,487.23

Sources: WIP/TU Berlin and DIW Berlin, 2023[1536]

In theory, a detailed evaluation of cost disparities across countries, technologies, and time can provide useful data to both higher-cost and lower-cost countries. For the former, review can identify potential areas for efficiency improvements; and for the latter, policymakers can assess whether some of the sources of cost savings result from design or oversight decisions that might introduce longer-term risks in other areas they should consider.

More challenging is if the OCC (and LCOE) data also differ across countries in part due to inconsistencies in how information is collected and reported. Every five years, IEA and NEA staff convene an Expert Group on Electricity Generating Costs to survey member countries' estimates of the future costs of generating electricity. These surveys are an important element feeding into the summary Table 19 above. While China is not a member of either organization, it is an affiliate country to the IEA. Further, IEA and NEA list Brazil, China, India, Romania, and Russia as participating countries in the report process.[1537] Indeed, "because of the importance of the Chinese nuclear power market, it has often been invited to participate, but China has never provided data".[1538] Rather, data for both China and India were "drawn from various publicly available sources".[1539]

1533 - Construction of the two-unit Mochovce project in Slovakia was originally started in 1985 and thus has a particularly long history of delays and cost overruns.

1534 - Leonard Göke, Alexander Wimmers and Christian von Hirschhausen, "Economics of Nuclear Power in Decarbonized Energy Systems", Workgroup for Infrastructure Policy (WIP), Technical University of Berlin, and Energy, Transportation, Environment Department, German Institute for Economic Research/Deutsches Institut für Wirtschaftsforschung (DIW), Preprint, 14 March 2023, p.37, see https://arxiv.org/pdf/2302.14515.pdf, accessed 22 July 2023.

1535 - Björn Steigerwald, Jens Weibezahn, Martin Slowik and Christian von Hirschuaen, "Uncertainties in estimating production costs of future nuclear technologies: A model-based analysis of small modular reactors", Workgroup for Infrastructure Policy (WIP), Technical University of Berlin, German Institute for Economic Research, Copenhagen School of Energy Infrastructure, and Institute of Mathematics of Mannheim, published in *Energy*, Vol. 281, 15 October 2023, see https://www.sciencedirect.com/science/article/pii/S0360544223015980, accessed 15 November 2023.

1536 - DIW and WIP, "Economics of Nuclear Power in Decarbonized Energy Systems", Preprint, 14 March 2023, op. cit., p.37.

1537 - IEA and OECD/NEA, "Projected Costs of Generating Electricity—2020 Edition", 2020, op. cit., p.13.

1538 - Geoffrey Rothwell, "Projected electricity costs in international nuclear power markets", *Energy Policy*, May 2022, op. cit., p.3.

1539 - IEA and OECD/NEA, "Projected Costs of Generating Electricity—2020 Edition", 2020, op. cit., p.26.

In their detailed review of five decades of cost escalation at U.S. nuclear power plants, researchers at the Institute for Data, Systems, and Society at the Massachusetts Institute of Technology (MIT) noted that reactor projects in China, Japan, Russia, and South Korea tended to have better construction performance than the U.S. and E.U. The authors remark that while faster build times (which these countries have) do tend to correlate generally with lower power costs, one should not draw strong conclusions because the "cost data from these countries are largely missing or are not independently verified."[1540]

This caveat is reinforced by a review of cost escalation and delays for 180 nuclear plant projects across multiple countries that found cost overruns occurring far more often than construction delays, "which does cast some doubt on the monotonic relationship between time overruns and cost overruns."[1541] Further, all reactors under construction as of 1 July 2023, in at least ten out of sixteen countries have had—mostly year-long—delays. As of mid-2023, over 40 percent of all projects were delayed, and of these, at least nine saw delays increase in the prior year.

Delays have been a factor even in the countries showing low OCCs. For example, of seven units in China that connected to the grid between 2019 and 2021, slightly more than half were either on time or less than a year late, but two reactors were around five years late. The four Russian reactors connecting to the grid during that same period were all significantly late, with delays of roughly 5–9 years before grid connection.[1542]

Overnight Capital Cost Metrics Lack Critical Variables to Assess Nuclear Competitiveness

In assessing the economic trajectory of nuclear as a perceived key lever of decarbonization, the overnight capital costs (OCC) metric suffers from some significant limitations. First, although cost of capital is frequently recognized as the single largest determinant of nuclear competitiveness,[1543] the OCC does not include it. Rubio-Varas notes that this "effectively excludes the most important costs of nuclear projects: the financing costs and the interest accumulating during the construction period."[1544] The impacts of this gap on nuclear power will be higher than on competing energy resources because nuclear has a longer lead time to

1540 - Philip Eash-Gates, Magdalena M. Klemun et al, "Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design", Institute for Data, Systems, and Society, and Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, published in *Joule*, Vol. 4, Issue 11, 18 November 2020, p. 2349, see https://doi.org/10.1016/j.joule.2020.10.001, accessed 21 July 2023.

1541 - Benjamin K. Sovacool, Daniel Nugent and Alex Gilbert, "Construction Cost Overruns and Electricity Infrastructure: An Unavoidable Risk?", *The Electricity Journal*, Vol. 27, Issue 4, May 2014, p. 115, see https://www.sciencedirect.com/science/article/abs/pii/S1040619014000761?via%3Dihub, accessed 21 July 2023.

1542 - Mycle Schneider, "World Nuclear Industry Status Report 2022+ (WNISR2022+)—With Particular Emphasis on Small Modular Reactors (SMRs)", 20 June 2023, as presented before the Committee on Energy, Environment and Climate, "Les SMR Dans Une Perspective Internationale", Hearing Proceedings, DOC 55 3460/001, Chamber of Representatives of Belgium, 27 June 2023, see https://www.lachambre.be/doc/FLWB/pdf/55/3460/55K3460001.pdf, accessed 21 July 2023.

1543 - MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World—An Interdisciplinary MIT Study", Massachusetts Institute of Technology, 2018, see https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf; and OECD/NEA, "Nuclear Operators' Third Party Liability Amounts and Financial Security Limits", Nuclear Energy Agency, Organization updated June 2022, p.16, see https://www.oecd-nea.org/upload/docs/application/pdf/2022-06/2020.10_operators_liability_amount_table_general_final_clean_v2_2022-06-30_13-34-34_716.pdf; both accessed 21 July 2023.

1544 - Mar Rubio-Varas, "Time is money, but sometimes it costs more: an economic history perspective into nuclear projects' pitfalls", *Journal of Mega Infrastructure & Sustainable Development*, July 2022, op. cit., p. 264.

start, and delays beyond that have been substantial in many countries. Past delivery problems have also driven up investor assessments of risk, and financing costs compound substantially with a higher cost of capital and longer build time. A comparative metric that ignores the critical variables of cost of capital and build time is unlikely to generate useful predictive results. In fact, MIT analysis viewed the cost of capital as determinative, noting that "[n]ew nuclear plants are not a profitable investment in the United States and Western Europe today. The capital cost of building these plants is too high."[1545]

Second, to the extent cost estimates embedded in the OCC are forward-looking, estimation errors on the assumed build cost are compounded because the actual project data on which to base these estimates are so limited. Newer designs are subject to "first-of-a-kind" (FOAK) risks associated with untested technologies, design development, regulatory and permitting costs, labor training, and so forth. In theory, these can be amortized over multiple reactor projects, reducing costs for later builds ("nth of a kind" or "NOAK"). But these gains are theoretical and aspirational at this point, particularly for the nuclear sector given that historically there have been no or even negative (where real costs increased with the number of units) learning curves.[1546]

Further, exactly what "*n*" would be sufficient to bring down the costs is hardly precise either. Projections range from five reactors to hundreds (see Table 21 below). Efficiency gains seem to arise with sequential construction of multiple identical units at the same site.[1547] However, empirical assessment indicated that NOAK cost reductions are "far from being a certain circumstance of repeatedly building a given design."[1548] The strongest example is the large French fleet, highly standardized and built under near-ideal conditions, yet with a learning curve observable only for the first few units, then reversing.[1549]

NuScale, an emerging manufacturer of SMRs that has yet to start construction of the first one, is targeting production of 672–1,680 "modules" by 2042.[1550] A plant can include up to 12 modules, so this target is roughly equivalent to 56–140 plants at a ~1 GW scale per multi-module plant. Learning from that level of production—wildly unrealistic if compared to any past experience and the current state of development—is assumedly flowing into the firm's cost projections. However, were it to achieve the upper end of its production target, NuScale alone would need to capture a significant portion of the global increase in nuclear capacity

1545 - MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World—An Interdisciplinary MIT Study", 2018, op. cit.

1546 - Jonathan Koomey and Nathan E. Hultman, "A Reactor-level analysis of busbar costs for U.S. nuclear plants, 1970-2005", *Energy Policy*, Vol. 35(11), pp. 5630-5642, see https://doi.org/10.1016/j.enpol.2007.06.005; and Nathan Hultman, Jonathan Koomey, and Daniel Kammen, "What History Can Teach Us About the Future Costs of U.S. Nuclear Power", *Environmental Science & Technology*, Vol. 41(7), pp. 2088–2093, 1 April 2007, see https://pubs.acs.org/doi/epdf/10.1021/es0725089; also Jonathan Koomey, Nathan E. Hultman, and Arnulf Grübler, "A reply to 'Historical construction costs of global nuclear power reactors'", *Energy Policy*, Vol. 102, pp.640-643, see https://doi.org/10.1016/j.enpol.2016.03.052.

1547 - MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World—An Interdisciplinary MIT Study", 2018, op. cit., and Koroush Shirvan, "Overnight Capital Cost of the Next AP1000", MIT-ANP-TR-193, Center for Advanced Nuclear Energy Systems, Massachusetts Institute of Technology, March 2022, p. 27, see https://web.mit.edu/kshirvan/www/research/ANP193%20TR%20CANES.pdf, accessed 21 July 2023.

1548 - MIT Institute for Data, Systems, and Society, "Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design", *Joule*, 18 November 2020, op. cit., p.2352.

1549 - Arnulf Grubler, "The costs of the French nuclear scale-up: A case of negative learning by doing", International Institute for Applied Systems Analysis, and School of Forestry and Environmental Studies, Yale University, published in *Energy Policy*, September 2010, see https://doi.org/10.1016/j.enpol.2010.05.003, accessed 8 November 2023.

1550 - Geoffrey Rothwell, "Projected electricity costs in international nuclear power markets", *Energy Policy*, May 2022, op. cit.

envisaged by the IEA through 2050. Further, even that level of production may not be sufficient to achieve the targeted cost savings: some analysts anticipate that even at the rates of learning projected for the nuclear industry, "the same SMR design will have to be manufactured by the thousands for the cost of electricity from SMRs to break even with the corresponding cost of electricity from large reactors" [1551], let alone with non-nuclear low-carbon competitors.

To the extent that reported OCC estimates often represent NOAK assumptions—which they do in the IEA estimates for nuclear—an additional level of imprecision has been added.

Table 21 · Moving Down the New-Build Cost Curve: What Is 'N'?

Reactor Type	Claimed Lot Size for NOAK	Projected Improvement
French (P4 series); South Korean (OPR-1000 reactor series)	10 reactors or more consecutively [(a)]	25% reduction in overall costs
Advanced nuclear reactors (U.S.)	10-20 reactor deployments [(b)]	Reduction of OCC from >US$10,000/kWe to US$3,600/kWe
Gen IV	Next plant after 8 GWe constructed; for fuel fabrication and reprocessing, 32 GWe for each reactor type [(c)]	
SMRs	At least 10 to 15 projects, i.e. between 3 GW and 4.5 GW of capacity for standard 300-MW modules [(d)]	
	Rolls-Royce, 470 MW SMR [(e)] 5 to 10 units	18% drop in total costs Business case based on "selling many hundreds" by 2050
	NuScale marketing targets are for between 56 and 140 "12-packs" by 2042 [(f)]	
	Production runs of hundreds or thousands of units [(g)]	

Sources: (a) MIT, 2022;[1552] (b) U.S. DOE, 2023;[1553] (c) Gen IV International Forum, 2007;[1554] (d) Wood Mackenzie, 2023;[1555] (e) Rolls-Royce, 2021; and Sampson, 2022;[1556] (f) Rothwell, 2022;[1557] (g) Glaser et. al., 2022[1558]

1551 - M.V. Ramana, "Small Modular and Advanced Nuclear Reactors: A Reality Check", University of British Columbia, as published in *IEEE Access*, revised 22 March 2021, see https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9374057, accessed 21 July 2023.

1552 - Koroush Shirvan, "Overnight Capital Cost of the Next AP1000", MIT-ANP-TR-193, Center for Advanced Nuclear Energy Systems, Massachusetts Institute of Technology, March 2022, see https://web.mit.edu/kshirvan/www/research/ANP193%20TR%20CANES.pdf, accessed 21 July 2023.

1553 - U.S. DOE, "Pathways to Commercial Liftoff: Advanced Nuclear", U.S. Department of Energy, United States Government, March 2023, see https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf, accessed 15 November 2023.

1554 - The Economic Modeling Working Group, "Cost Estimating Guidelines for Generation IV Nuclear Energy Systems, Revision 4.2", GIF/EMWG/2007/004, Generation IV International Forum, 26 September 2007, see https://www.gen-4.org/gif/upload/docs/application/pdf/2013-09/emwg_guidelines.pdf, accessed 29 August 2023.

1555 - David Brown, "The Nuclear Option: Making New Nuclear Power Viable in the Energy Transition", Energy Transition Practice, Wood Mackenzie, May 2023, p.8, see https://go.woodmac.com/l/131501/2023-05-11/2z7ft5/131501/1683787920TDeRmpBv/Wood_Mackenzie_Thought_Leadership_Horizons_The_Nuclear_Option.pdf; accessed 21 July 2023.

1556 - Rolls-Royce SMR, "More power and updated design revealed as nuclear power team targets first place in the assessment queue in Autumn 2021", 17 May 2021, see https://www.rolls-royce-smr.com/press/more-power-and-updated-design-revealed-as-nuclear-power-team-targets-first-place-in-the-assessment-queue-in-autumn-2021; and Tom Sampson, "Corrected oral evidence: UK energy supply and investment", Transcript, CEO of Rolls-Royce SMR, before the Economic Affairs Committee of the House of Lords, 5 April 2022, see https://committees.parliament.uk/oralevidence/10083/html/, accessed 20 September 2023, and Tom Sampson, "Oral evidence: Delivering nuclear power" HC 626, Rolls-Royce, Before the Science & Technology Committee, House of Commons, 23 November 2022.

1557 - Geoffrey Rothwell, "Projected electricity costs in international nuclear power markets", *Energy Policy*, Vol.164, May 2022, p.6, see https://doi.org/10.1016/j.enpol.2022.112905, accessed 21 July 2023.

1558 - Alexander Glaser, M.V. Ramana et. al., "Small Modular Reactors: A Window on Nuclear Energy", Andlinger Center for Energy and the Environment, Princeton University, June 2015.

Nuclear Power Has a Long History of Cost Escalation

Nuclear power plants and fuel chain facilities are "megaprojects"—a group of activities that are among the most complex, expensive projects that humans have taken on. They tend to have long build times, sensitive to many types of delays also earlier in the process. Bent Flyvbjerg and colleagues at Oxford University have been tracking megaprojects for decades. In their database on megaproject cost overruns, nuclear waste storage facilities were at the top of the list with mean cost overruns of 238 percent, and nuclear power plants were third with a mean cost overrun of 120 percent. Fifty-five percent of the assessed nuclear power plants had cost overruns at or exceeding 50 percent.[1559] Flyvbjerg wrote that if nuclear power is to succeed it needs to "break the current vicious circle of negative learning and crack the code of smart scale-up, with its modularity, replicability, and positive learning-by-doing".[1560] However, the history of cost escalation argues for caution in assuming that nuclear LCOE estimates incorporating projected learning in their NOAK costs will be at all reliable in predicting future industry competitiveness.

Even assuming this challenging goal on cost improvements can be met, the gains for nuclear do not, and will not, occur in isolation. Structurally, the nuclear sector's much smaller lot sizes inherently constrain gains from replicability and positive learning-by-doing. This limitation may result in slower, and smaller, cost improvements than will be realized by its competitors, such as Small Modular Renewables.

Consider that, as of mid-2023, there were 407 reactors operating around the world. Reactors under construction comprise the most relevant group on which learning and cost improvements occur but numbered only 58. As Flyvbjerg notes, growth in smaller, modular reactor units may somewhat improve the opportunity for learning and innovation. Current trends, however, suggest that the ramp up is likely to be slow and the scale still small. At present there are only four modules in operation and five in construction worldwide.

Within this grouping, both cost escalation and construction delays in the early SMR projects have already been significant (see other sections of the report and earlier WNISR editions). The now abandoned NuScale SMR project in Utah, for example, comprised six 77 MW reactors with initial grid connection planned by 2029 at a cost of US$58/MWh. The estimated cost had then further risen to US$89–100 MWh, attributed to higher steel prices and interest rates,[1561] before the project partners pulled the plug, in early November 2023.[1562] The project would have benefited from more than US$4 billion in federal subsidies from the Inflation Reduction

1559 - Bent Flyvbjerg and Dan Gardner, "How Big Things Get Done— The Surprising Factors That Determine the Fate of Every Project, from Home Renovations to Space Exploration and Everything In Between", *Penguin Random House*, 7 February 2023, p.192, see https://www.penguinrandomhouse.com/books/672118/how-big-things-get-done-by-bent-flyvbjerg-and-dan-gardner/, accessed 21 June 2023.

1560 - Bent Flyvbjerg, "Make Megaprojects More Modular", *Harvard Business Review*, November-December 2021, pp. 58-63.

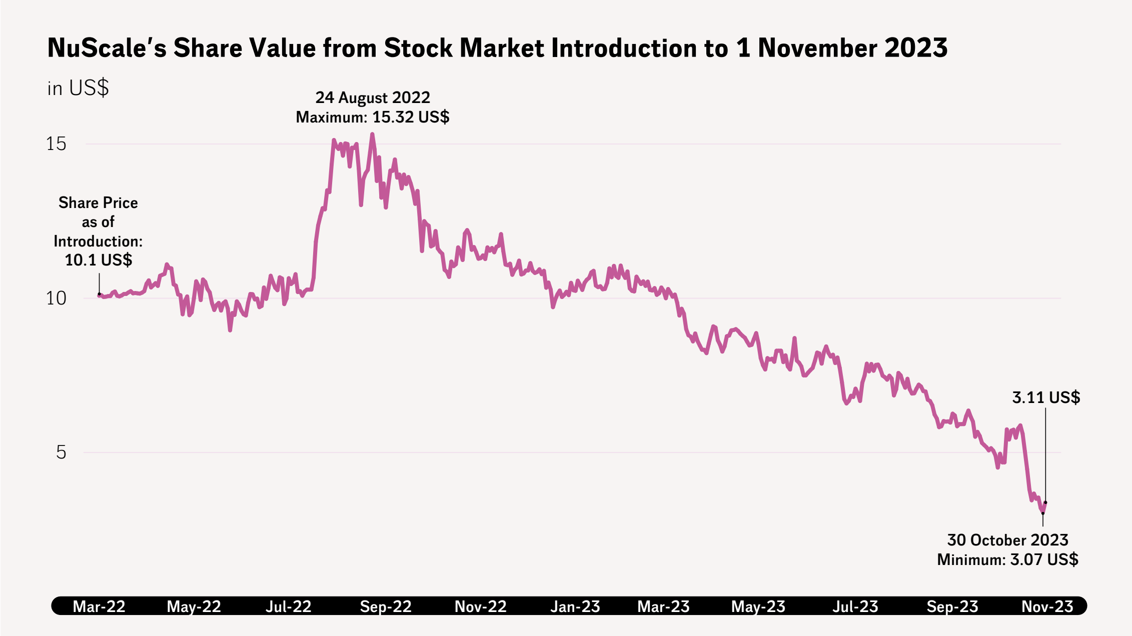
1561 - Robert Walton, "Rising steel prices, interest rates could push NuScale Utah project cost to $100/MWh, but support remains", *Utility Dive*, 16 November 2022, see https://www.utilitydive.com/news/nuscale-nuclear-reactor-smr-uamps-rising-steel-prices-interest-rates/636619/, accessed 6 June 2023.

1562 - NuScale, "Utah Associated Municipal Power Systems (UAMPS) and NuScale Power Agree to Terminate the Carbon Free Power Project (CFPP)", Press Release, 8 November 2023, see https://nuscale-prod-pbpdt9uqe-nuscale-power.vercel.app/en/news/press-releases/2023/uamps-and-nuscale-power-agree-to-terminate-the-carbon-free-power-project, accessed 9 November 2023.

Act (IRA) alone,[1563] and without that subsidy was estimated to cost up to US$120/MWh.[1564] All risk of cost overruns was contractually assigned to customers.

The cost escalation is a replay of earlier waves of nuclear construction, and risks dampening enthusiasm for continued investment, even by insiders. Stock transactions by NuScale (ticker "SMR") insiders such as firm executives and board members must be reported to the U.S. Securities and Exchange Commission. Between June 2022 and June 2023, there were 47 insider stock sales and only one stock purchase.[1565] In little more than a year, NuScale's share value plunged by more than 80 percent from its peak at US$15.32 in August 2022 to US$2.56 on 15 November 2023 (see Figure 58). In October, short-seller Iceberg Research alleged material mispresentations in NuScale announcements related to contracts and customer strength, as well as highlighted additional financial challenges from anticipated delivery delays in part from design changes.[1566] NuScale has rebuffed the claims,[1567] though the stock has remained under pressure, especially since NuScale announced the termination of the Utah project on 8 November 2023 (see section on the United States in the chapter on SMRs).

Figure 58 · NuScale's Share Value History



Sources: Yahoo Finance, November 2023

1563 - David Schlissel, "Small modular reactor project likely to end badly for utilities and worse for taxpayers", Director of Resource Planning Analysis, Institute for Energy Economics and Financial Analysis, see https://ieefa.org/resources/small-modular-reactor-project-likely-end-badly-utilities-and-worse-taxpayers, accessed 21 July 2023.

1564 - Robert Walton "Rising steel prices, interest rates could push NuScale Utah project cost to $100/MWh, but support remains", *Utility Dive*, 16 November 2022, op cit.

1565 - GuruFocus Research, "CFO Chris Colbert Sells 89,786 Shares of NuScale Power Corp (SMR)", 27 June 2023, see https://www.gurufocus.com/news/2029412/cfo-chris-colbert-sells-89786-shares-of-nuscale-power-corp-smr, accessed 7 August 2023.

1566 - Iceberg Research, "NuScale Power ($SMR): A Fake Customer and a Major Contract in Peril Cast Doubt on NuScale's viability", 19 October 2023, see https://iceberg-research.com/2023/10/19/nuscale-power-smr-a-fake-customer-and-a-major-contract-in-peril-cast-doubt-on-nuscales-viability/, accessed 7 November 2023.

1567 - NuScale, "NuScale Power Comments on Inaccurate Short-Seller Report", Press Release, 24 October 2023, see https://www.nuscalepower.com/en/news/press-releases/2023/nuscale-power-comments-on-inaccurate-short-seller-report, accessed 7 November 2023.

The IEA is more optimistic in its assessment, referring to a "burst" of activity in SMRs, and roughly 25 units in the basic or detailed design phase and close to 40 in conceptual design.[1568] Yet, as with all complex new innovations, high levels of attrition should be expected between concept and delivery of producing plants. These risks seem particularly high given the presence of many newcomers without prior experience in reactor building.

Further, developing multiple new reactor concepts concurrently exacerbates the already formidable challenges facing SMRs. For example, it will be more difficult to attain sufficient builds for each design to achieve NOAK costs with orders spread across multiple technologies. In addition, specialized requirements for enrichment and waste management complicate the innovation cycle and significantly increase both system costs and ramping time for some of the designs. The U.S. National Academy of Sciences, Engineering and Medicine (NASEM) notes that transition to alternative fuel chains is anticipated to take 50 to 100 years,[1569] a time frame that would entirely miss the most important decades for climate stabilization. The delivery and cost risks here were deemed sufficiently worrying for NASEM to flag them, arguing that the U.S. Department of Energy needed to select just a few designs to increase the chances it could move them to deployment by 2050.[1570] It is noted that 2050 is also the target date for economies to be net zero carbon under many of the climate stabilization plans, so starting deployment of reactors at that point misses the critical decarbonization period. Indeed, U.S. DOE considers more than 80 percent U.S. low-carbon electricity generation feasible by 2030 and 100 percent in 2035, sooner than any material number of SMRs or any newbuild nuclear could be deployed.

The production scales of nuclear's main competitors are in entirely different orders of magnitude. The installed base of wind turbines is more than 300,000 globally, with more than 25,000 installed in 2022 alone.[1571] PV module (each panel has multiple modules) production was "well over" 300 GW in 2022[1572], which translates to a unit count in the hundreds of millions per year[1573].

Power storage is also scaling at a dizzying rate. Production of batteries for EVs increased more than 27-fold between 2016 and 2022, to over 500 GWh/year.[1574] Grid-scale battery storage

1568 - Brent Wanner, "Nuclear Power Technologies in IEA Scenarios", Head of Power Sector Unit, International Energy Agency, presented before the Committee on Energy, Environment and Climate, "Les SMR Dans Une Perspective Internationale", Hearing Proceedings DOC 55 3460/001, Chamber of Representatives of Belgium, 27 June 2023, p. 68, see https://www.lachambre.be/doc/FLWB/pdf/55/3460/55K3460001.pdf, accessed 21 July 2023.

1569 - NASEM, "Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors", National Academies of Sciences, Engineering, and Medicine, 2023, see https://doi.org/10.17226/26500, accessed 21 July 2023.

1570 - Ibidem, p. 54.

1571 - Installed capacity is from GWEC, "Global Wind Report 2023", Global Wind Energy Council, 27 March 2023, p. 14, see https://gwec.net/wp-content/uploads/2023/04/GWEC-2023_interactive.pdf, accessed 15 July 2023.

Estimated turbine counts assume 3 MW/turbine, reflecting the capacity of new installations in the U.S., based on Office of Energy Efficiency & Renewable Energy, "Wind Turbines: the Bigger, the Better", U.S. Department of Energy, 16 August 2022, see https://www.energy.gov/eere/articles/wind-turbines-bigger-better, accessed 7 August 2023.

Turbine capacity has been rising annually for the past two decades, so the average capacity of installed turbines will be lower than the most recent and the actual turbine count therefore higher. The figure listed here should be viewed as a floor.

1572 - Jules Scully, "Top 10 PV module suppliers in 2022 shipped 245GW", *PV Tech*, 1 February 2023, see https://www.pv-tech.org/top-10-pv-module-suppliers-in-2022-shipped-245gw/, accessed 6 September 2023.

1573 - IEA, "Special Report on Solar PV Global Supply Chains", International Energy Agency, Revised August 2022, see https://iea.blob.core.windows.net/assets/d2ee601d-6b1a-4cd2-a0e8-db02dc64332c/SpecialReportonSolarPVGlobalSupplyChains.pdf, accessed 23 July 2023.

1574 - IEA, "Global EV Outlook 2023", April 2023.

added in 2022 was 11.1 GW, up from a base of only 2 GW in 2015.[1575] Despite being an industry still early in its growth phase, grid-scale batteries added more capacity than the 7.4 GW of new nuclear capacity connected to the grid in 2022. U.S. EIA projects 2023 additions in the U.S. of 25.2 GW solar, 9.6 GW battery storage, 8.1 GW wind, 7.8 GW natural gas, and 1.25 GW nuclear (Vogtle 3)—a total of 52 GW, *vs.* 15.3 GW of fossil-fuel retirements.[1576]

And while innovations in smaller batteries won't move directly to utility-scale storage, these markets nonetheless provide opportunities to refine technical knowledge on battery chemistries and manufacturing techniques, expand the technical researcher base, and often share mineral supply chains. In 2021 alone, more than 1.4 billion cell phones were sold, and in 2022, more than 375 million portable computing devices—all with batteries.[1577]

TRENDS IN NUCLEAR LCOE ESTIMATES

In addition to OCC estimates, energy comparisons are frequently presented on a Levelized Cost of Energy (LCOE) basis. This approach incorporates operating costs, build times, load factors, and discount rates to generate an average cost per unit energy produced over the plant's lifetime. The LCOE provides a more accurate comparison of high load factor resources such as nuclear with lower load factor renewables, since the higher fixed costs per unit energy generated will increase the LCOE of variable energy sources. Similarly, the cost impacts of longer build times can also be captured because financing costs (and delays in the sale of kWh) can be integrated into project costs as well.

LCOE assessments are normally conducted using the same cost of capital for all energy resources, which simplifies comparisons across energy options and over time. However, market investors would likely require a higher return for riskier investments. Emerging technologies, such as coal with CCS; or energy technologies with historical cost overruns and delivery delays, such as nuclear, are riskier for investors and should likely have a higher discount rate than other resources.

Government may offer preferential credit rates to favored solutions (via lending or other programs, or through direct ownership). Yet, "shifting the risk does not magically reduce the financing cost; the government's cost-of-capital is not necessarily less than [that of] private investors."[1578] Instead, it often means that the government entity is providing a larger credit subsidy to the riskier beneficiary, not that risks are somehow more effectively managed. Differential provision of subsidized credit often leads to competitive distortions across

1575 - IEA, "Grid-scale Storage", International Energy Agency, Updated 11 July 2023, see https://www.iea.org/energy-system/electricity/grid-scale-storage, accessed 26 November 2023.

1576 - EIA, "Developers added 16.8 GW of U.S. utility-scale generating capacity in first-half 2023", 8 August 2023, see https://www.eia.gov/todayinenergy/detail.php?id=57340, accessed 5 November 2023.

1577 - Statista, "Number of smartphones sold to end users worldwide from 2007 to 2022", 21 July 2023, see https://www.statista.com/statistics/263437/global-smartphone-sales-to-end-users-since-2007/; and Statista, "Personal computing devices shipments worldwide from 2022 to 2027", 8 June 2023, see https://www.statista.com/statistics/272595/global-shipments-forecast-for-tablets-laptops-and-desktop-pcs/; both accessed 23 July 2023.

1578 - John Parsons, "Madness vs Wisdom of Crowds: Models for Financing Nuclear Power", Massachusetts Institute of Technology, 14 January 2021, presented at OECD/NEA, "Issues in the Financing of Nuclear New Build", International Framework for Nuclear Energy Cooperation Financing Initiative, Nuclear Energy Initiative, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, 14-15 January 2021, see https://www.oecd-nea.org/jcms/pl_53044/madness-vs-wisdom-of-crowds-models-for-financing-nuclear-power?details=true, accessed 21 July 2023.

different energy or decarbonization pathways. A "fair value" approach to assessing the cost of credit would greatly reduce this problem by pricing risk relative to the market rather than to the Treasury's generic cost of borrowing independent of borrower risk. Most often, however, "governments (and government-owned entities) systematically understate the costs of credit support, often by a considerable margin".[1579]

While LCOE presentations assume the same discount rate for all technologies, there is at least some recognition that the discount rate for nuclear should be higher. For example, IEA notes that

> Conventional nuclear plants are large and highly capital-intensive, involving long lead times and complex construction works. These risks directly affect the cost of capital, and ultimately the levelised cost of electricity, by increasing the returns demanded by investors to account for them.[1580]

Both IEA (see Figure 59 below) and Lazard run a sensitivity analysis on the cost of capital, allowing a more nuanced comparison of energy options. The baseline within IEA's analysis includes a US\$30/tCO_2 carbon price for natural gas and coal options, as well as assuming NOAK costs for the LCOE of newbuild nuclear.[1581] Both assumptions improve the reported competitive positioning of nuclear.

Yet, even with these favorable adjustments, the sensitivity of nuclear to the real discount rate is quickly evident. The resource has the lowest LCOE at a zero discount-rate (roughly equivalent to the overnight cost of capital plus operating costs) but begins to be outcompeted by gas at discount rates of around 5 percent/year. At the upper range of a 20 percent/year real cost of capital, nuclear is by far the most expensive, and its median LCOE has jumped five-fold relative to the resource's lower bound cost.[1582] While 20 percent real may seem an excessively high discount rate, target hurdle rates for high-risk venture capital and private equity (a source of capital for some of the new SMR funding) are often around this level.

Also notable in the chart is the tight LCOE cost band for nuclear with no discount rate in comparison to the much larger spread in both of the OCC summary tables (Table 19 and Table 20) above. This may be an artifact of excluding the high cost, upper tier of the distribution which the other sources capture. The wide variability in possible outcomes that exists in the full data on these projects is a reminder that the projects can go very wrong financially, spooking investors, and affecting both the availability and cost of capital to new nuclear projects.

Lazard's analysis of U.S.-focused costs also includes a sensitivity graph mapping unsubsidized LCOE against discount rates.[1583] The cost of capital range was narrower (4.2 to 10 percent versus 0 to 20 percent in the IEA analysis), though the findings were broadly similar. Aside from natural gas peaking plants at discount rates of less than 5.4 percent, Lazard's estimates indicate that nuclear is always the most expensive resource on an LCOE basis. At a discount

1579 - Deborah Lucas, "Evaluating the Cost of Government Credit Support: The OECD Context", Massachusetts Institute of Technology, published in *Economic Policy*, July 2014, p.556, see https://mfm.uchicago.edu/wp-content/uploads/2020/07/Lucas-Evaluating-the-Cost-of-Government-Credit-Support-The-OECD-Context.pdf, accessed 21 July 2023.

1580 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.21.

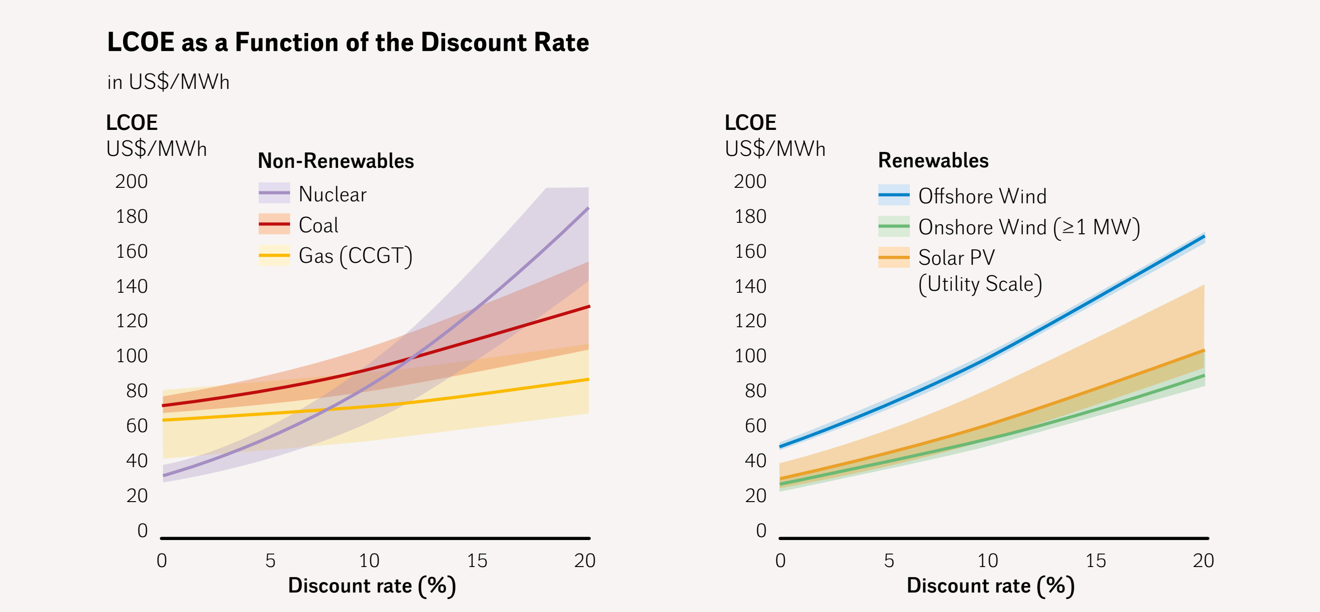
1581 - IEA and OECD/NEA, "Projected Costs of Generating Electricity—2020 Edition", 2020, op. cit., p.14 and 39.

1582 - Ibidem, p.84.

1583 - Lazard, "LCOE+", April 2023, op. cit., p.6.

rate of 10 percent, and excluding firming costs, nuclear is nearly 4 times the LCOE of onshore wind.

Figure 59 • LCOE as a Function of Discount Rate – Non-Renewables vs. Renewables



Source: IEA and OECD/NEA, 2020[1584]

Note: Lines indicate median values, areas the 50% (20% for renewables) central region.

Comparing Nuclear LCOE Estimates

LCOE estimates are frequently used to illustrate the competitiveness of different energy pathways. However, there can be significant variation for this metric across data sources and over time as well, making evaluation of trends more challenging. Using just data on nuclear LCOE from the *same* IEA cost survey, for example, a number of factors contributed to data consistency challenges.[1585] These included data from some countries originating from public reporting rather than surveys of country experts and officials; use of standardized assumptions rather than actual values for Operation and Maintenance (O&M) across multiple countries (and perhaps omission of Net Capital Additions in some cases); use of NOAK projections that probably have a fairly high level of uncertainty; and differences in the type of reactor being installed. LCOE estimates produced by different analysts have added variability from factors such as what cost of capital they view as the central case, and potentially different estimates for OCC and build time as well.

Table 22 below summarizes data from five analyses, three of which were done for the IEA. These include multiple IEA estimates from its five-year projections of power-plant

1584 - IEA and OECD/NEA, "Projected Costs of Generating Electricity—2020 Edition", 2020, op. cit., p.84.

1585 - Geoffrey Rothwell, "Projected electricity costs in international nuclear power markets", Energy Policy, May 2022, op. cit.

costs, as adjusted by Geoffrey Rothwell (2022);[1586] Lazard's U.S. estimate over time;[1587] the DIW/WIP meta-analysis of 88 reactor projects (2023), which included the IEA dataset plus many others;[1588] and IEA LCOE cost evaluations in separate 2021 and 2022 assessments.[1589] A 2023 update to IEA's Net Zero Roadmap included increased targets for nuclear capacity in 2050, but did not include updated LCOE data.[1590]

Of note in the table are large shifts in IEA estimates between 2015 and 2020. LCOE estimates—even within the OECD—dropped despite significant cost escalation for reactors under construction in both the U.S. and Europe. This is counter-intuitive, and perhaps reflects the use of optimistic NOAK values. Further, mean LCOE values in the IEA data were less than two-thirds the estimate in the DIW/WIP analysis from a larger sample; and they were less than half the estimates in Lazard for the U.S. Also intriguing is that separate estimates of nuclear LCOE done in its Net Zero by 2050 analysis and later in its 2022 "World Energy Outlook" were significantly higher. These are also NOAK estimates, though they use a higher discount rate (8 percent). Other causes for the sharp increases at least within the U.S. and E.U. values (those for China and India did not change very much) seem to be associated with shifts in the overnight capital cost estimates, though the drivers are not clear from the published data.

The IEA data compiled by Rothwell also diverged from the Lazard data for the U.S. due to the cost of capital (7.7 percent versus 5 percent) in the central case presented. There is no discussion on whether even Lazard's cost of capital is too low for newbuild nuclear. NERA, for example, estimated the hurdle rate for new nuclear in the U.K. at 9.7–13.6 percent real;[1591] and government involvement with all or nearly all reactor projects in the world means that empirical estimates of the true market-based cost of capital are impossible to attain.

The nuclear LCOE in Lazard's dataset is primarily based on the two new Vogtle reactors in the U.S. state of Georgia. Cost escalation was enormous on that project: from US$13 billion in 2009 to US$35 billion by 2022 on a nominal dollar basis, with a doubling since 2015.[1592] In this regard, IEA's declining real LCOE between 2015 and 2023 is also surprising. More than one-fifth of DOE's reported build costs were financing costs.[1593] And with Vogtle, the true total was much larger since in addition to long delays and large cost overruns, the data exclude the large subsidies to the reactors through highly favorable terms for credit provided both from

1586 - Ibidem.

1587 - Lazard, "LCOE +", 12 April 2023, see https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/, accessed 15 June 2023.

1588 - DIW and WIP, "Economics of Nuclear Power in Decarbonized Energy Systems", Preprint, 14 March 2023, op. cit.

1589 - IEA and OECD/NEA, "Projected Costs of Generating Electricity—2020 Edition", 2020, op. cit.; and IEA, "Net Zero by 2050: A Roadmap for the Global Energy Sector", Revised October 2021, see https://www.iea.org/reports/net-zero-by-2050; and IEA, "World Energy Outlook 2022", Revised November 2022, pp. 469-471, see https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf; both accessed September 2023.

1590 - IEA, "Net Zero Roadmap A Global Pathway to Keep the 1.5 °C Goal in Reach: 2023 Update", September 2023, op. cit.

1591 - Richard Hern, Daniel Radov et al., "Electricity Generation Costs and Hurdle Rates—Lot 1: Hurdle Rates update for Generation Technologies", NERA Economic Consulting, prepared for the UK Department of Energy and Climate Change, July 2015, see https://www.nera.com/content/dam/nera/publications/2016/NERA_Hurdle_Rates_for_Electricity_Generation_Technologies.pdf, accessed 21 July 2023.

1592 - U.S. DOE, "Pathways to Commercial Liftoff: Advanced Nuclear", U.S. Department of Energy, 20 March 2023, op. cit., p.29.

1593 - Ibidem.

the U.S. Treasury (roughly US$12 billion in subsidized loans from DOE)[1594] and the interest-free advance payments from the utility's own customers through construction work in process (CWIP) rules. CWIP payments totaled US$3.5 billion through December 2020, and were borne much more heavily by residential than industrial customers.[1595]

In 2020, the French Court of Accounts calculated the total cost of the Flamanville EPR at €$_{2015}$19.1 billion (US$_{2015}$21 billion), including €$_{2015}$12.4 billion (US\$$_{2015}$13.8 billion) overnight capital costs—up from the pre-construction €$_{2001}$2.8 billion (US\$$_{2001}$2.5 billion) estimate—and €$_{2015}$4.22 billion (US\$$_{2015}$4.6 billion) or 22 percent for financing costs, €$_{2015}$3 billion (US\$$_{2015}$3.3 billion) more than planned. Production costs of the reactor were put at €$_{2015}$110–120/MWh (US\$$_{2015}$122–133/MWh) for an availability factor of 90–80 percent.[1596] Those estimates assumed commissioning on 1 July 2023, which did not happen.

IEA's reliance on NOAK likely creates significant estimate uncertainty. The DIW/WIP analysis found a huge spread in overnight capital costs (US$1,914–12,600/kW). Of particular interest were the differences between projected costs and those tabulated from actual completed projects. Actual build times for recent and ongoing projects within OECD countries were 10–17 years (the team had inadequate data access to generate comparable data from non-OECD countries) versus projected construction periods of 5–9 years.[1597] Further, the future projections for LWRs were far lower than current experience on what those projects have actually cost to build: US$5,122/kW median for projected costs versus US$9,250/kW median (80 percent higher) for real costs incurred. The cost overage was not limited to median values in the sample set; rather, it was roughly similar for the projects at both the lower cost end (25th percentile) and the higher cost range (75th percentile) in the distribution, at 1.88 and 1.63 respectively.[1598] This suggests a broad-based problem across many reactor projects.

It is notable that where IEA projected forward values in 2050, when the LCOE for nuclear declined, it often dropped very little, except for E.U. reactors were declines approached (at most) 25 percent between 2020/21 and 2050. Projected declines in LCOE for offshore wind and solar PV were much higher in all scenarios. Even when IEA adjusted variable renewable (wind and PV) energy sources for their "value" to reflect system costs, offshore wind continued to show large declines. Solar PV showed cost increases, but in just about every case remained less expensive than nuclear.[1599]

The IEA's opaque "value" adjustments use a modeling approach similar to that used by DOE, MIT, and Princeton, with some common weaknesses. Such models generally omit many important grid-balancing technologies that could reduce the system integration costs for variable renewables significantly, and in some cases incur *lower* system integration costs

1594 - Jigar Shah, "How the Loan Programs Office and Plant Vogtle are Shaping the Energy Transition through Nuclear Technology", Director Loan Programs Office, U.S.DOE, 28 October 2022, see https://www.energy.gov/lpo/articles/how-loan-programs-office-and-plant-vogtle-are-shaping-energy-transition-through, accessed 21 July 2023.

1595 - Georgia Conservation Voters, "Ratepayer Robbery – The True Cost of Plant Vogtle", December 2021, see https://saportareport.com/wp-content/uploads/2021/12/GCV-Vogtle-Ratepayer-Robbery-Report-2.pdf, accessed 19 July 2023.

1596 - Cour des comptes, "La filière EPR", French Court of Audit, 9 July 2020 (in French), see https://www.ccomptes.fr/fr/publications/la-filiere-epr, accessed 6 September 2023.

1597 - DIW and WIP, "Economics of Nuclear Power in Decarbonized Energy Systems", Preprint, 14 March 2023, op. cit., p. 3.

1598 - Ibidem, p.3 and 38.

1599 - IEA, "Net Zero by 2050", op. cit., Table B.1, p. 201; and IEA, "World Energy Outlook 2022", op. cit., Tables B.4a – B.4c, pp. 469-471.

than large thermal stations.[1600] The driver is that big thermal plants' forced outages are larger, longer, and less predictable than the forecastable variations of solar and wind output, and therefore incur higher firming or backup costs, notably reserve margin, spinning reserve, part-load penalties, and cycling costs. Therefore, the frequent claim that counting grid integration costs would turn new nuclear power from costlier to cheaper than wind and solar power appears contradicted by empirical data. That data often hints to a *larger* total-cost gap favoring renewables, or indicate at least fairly negligeable grid integration costs for renewables if compared with the increasingly large cost advantage over nuclear power.[1601]

Table 22 · Nuclear LCOE Estimates (in US$2018)

	US$/MWh			Discount rate	Notes
	2015	2020–2022	2023		
IEA Electricity Survey (Rothwell 2022)					China and India based on public data; 2020 estimates are NOAK for a 2025 reactor.
OECD mean	71	62		5% real	
Non-OECD mean	34	51		5% real	China only for 2015; Russia and India as well for 2020.
IEA Net Zero by 2050					NOAK
U.S.		102		8% real	2020 estimate
E.U.		145		8% real	2020 estimate
China		63		7% real	2020 estimate
India		73		7% real	2020 estimate
IEA 2022 and 2023 World Energy Outlooks					
U.S.		87–92		8–9% real	Range includes all three IEA scenarios
E.U.		128–132		8–9% real	Range includes all three IEA scenarios
China		54-60		7–8% real	Range includes all three IEA scenarios
India		58–69		7–8% real	Range includes all three IEA scenarios
DIW/WIP (2023) Meta-Analysis					
	82	100		5% real	Based on review of 88 reactor projects, which also include the IEA and Lazard estimates among them.
Lazard (2023) - U.S. data					
	159	158	148	7.7%, assume real	Largely based on Vogtle; does not make sense real LCOE estimate is declining.

Sources: Rothwell, 2022; DIW and WIP, 2023; Lazard, 2023; IEA Net Zero, 2021; IEA WEO, 2022; IEA WEO, 2023[1602]

Notes: **NOAK**: Nth-of-a-kind.

1600 - Amory Lovins, comments, November 2023, on David Roberts, "What? The sun isn't always shining?!", interview with Jesse Jenkins, Princeton University, on *Volt*, 1 November 2023, see https://www.volts.wtf/p/what-the-sun-isnt-always-shining?publication_id=193024#details, accessed 5 November 2023.

1601 - Amory B. Lovins, "US nuclear power: Status, prospects, and climate implications", *The Electricity Journal*, 1 May 2022, op. cit.

1602 - Geoffrey Rothwell, "Projected electricity costs in international nuclear power markets", *Energy Policy*, Vol 164, May 2022, op. cit.; and DIW and WIP, "Economics of Nuclear Power in Decarbonized Energy Systems", Preprint, 14 March 2023, op. cit.; and Lazard, "LCOE+", April 2023, op. cit.; and IEA, "Net Zero by 2050: A Roadmap for the Global Energy Sector", Revised October 2021, op. cit.; also IEA, "World Energy Outlook 2022", Revised November 2022 op. cit.; and International Energy Agency, "World Energy Outlook 2023", October 2023, op. cit.

Capital-intensive investments tend to suffer during periods of rising inflation and associated interest rates. For mortgages, this results in significantly higher monthly payments.[1603] For assets such as nuclear plants, there are long periods between the start of construction and the flow of revenues, during which financing charges can compound sharply. This affects nuclear more than other energy resources because of a longer build time (resulting in more compounding) and a higher cost of capital (where it is not subsidized by government policy). High inflation has been considered a significant factor in the demise of many nuclear projects in the U.S. during the 1970s and 80s:

> High interest rates in the late 1970s and early 1980s meant the collapse of America's ambitious nuclear construction program and the cancellation of many partially built plants. Of all power generation options, capital-intensive nuclear power is the most sensitive to interest rates.[1604]

Interestingly, although the IEA's updated nuclear LCOE scenarios for 2022 were higher than in earlier years on a nominal basis, the most recent data showed declining costs on a real dollar basis in the U.S., despite higher inflation and financing costs.[1605] The reason for this shift is not clear.

Lower nuclear LCOEs in China, Russia, South Korea, and a few other countries have been of great interest. Lower cost labor in China and South Korea have been flagged as one source of advantage,[1606] allowing a larger staff that, in turn, facilitates more shadowing and apprenticeship to build skills for future projects. Failure of construction management approaches are viewed as a significant source of cost escalation in the U.S. and Europe as compared to projects in China, South Korea, and the United Arab Emirates. However, limited data availability has prevented full estimates of LCOEs in many countries by disinterested parties.

Further, many of these competitive advantages should not be evaluated in isolation as they apply at least equally to other forms of energy as well. For example, Chinese wind and solar were well below the cost of Chinese nuclear on a levelized cost/MWh basis, "so China invested at least as much in renewables in 2020 as it had invested *cumulatively* in nuclear power during 2008–20, adding half the world's 2020 new renewable capacity and 80% of the global increase over 2019's."[1607]

MISSING COSTS

Beyond the nuclear generating station, there are ancillary requirements of the nuclear fuel chain that are more expensive and more complex than for most other forms of energy. These other elements are not always well-captured in the economic evaluations of the resource,

1603 - Alex Veiga, "Elevated mortgage rates are leading to sharply higher monthly payments even as home prices ease", *The Associated Press*, 6 July 2023, see https://apnews.com/article/mortgage-payment-home-loans-home-prices-affordability-d31e9074ac7a0ebf9950167344b55920, accessed 11 August 2023.

1604 - Joseph Somsel, "How the Fed will Strangle New Nukes", *American Thinker*, 14 September 2022, see https://www.americanthinker.com/articles/2022/09/how_the_fed_will_strangle_new_nukes.html, accessed 11 August 2023.

1605 - IEA, "World Energy Outlook 2023", International Energy Agency, October 2023, see https://iea.blob.core.windows.net/assets/66b8f989-971c-4a8d-82b0-4735834de594/WorldEnergyOutlook2023.pdf, accessed 7 November 2023.

1606 - MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World", 2018, op. cit., p. 39.

1607 - Amory B. Lovins, "US nuclear power: Status, prospects, and climate implications", *The Electricity Journal*, Vol. 35, Issue 4, May 2022, p.4, see https://doi.org/10.1016/j.tej.2022.107122, accessed 21 July 2023.

and explicitly excluded in some assessments. This language from a recent review of nuclear energy's viability by the Massachusetts Institute of Technology (MIT) is an example:

> This study does not address the disposal of radioactive waste (or, more properly, spent nuclear fuel) or proliferation risks. While these issues are universally considered barriers to the expansion of nuclear energy use, the political dimensions of finding solutions to waste disposal and managing proliferation risks far outweigh the technical challenges.[1608]

A blanket exclusion is problematic, since many other analysts see significant technical challenges, not just political ones, and because many alternative energy pathways do not incur either the political or economic dimensions challenging nuclear.

This section looks at the economics of decommissioning, nuclear waste management, accident liability, and energy security and proliferation concerns at a high level. Other chapters in this report provide more details on specific programs and countries.

Costs appear to be overlooked for two main reasons: the activity is difficult to estimate, and therefore estimates are inaccurate; or the activity is expensive, long-term, and/or risky, and has been shifted from the private cost calculation onto the state. Both can result in underestimating the full cost of nuclear and creating increased competitive barriers to other forms of energy.

Accruals for Decommissioning Appear Too Low, Often State-Funded

Facility decommissioning is an Asset Retirement Obligation (ARO). AROs are not unique to nuclear power, and commonly include large end-of-lifetime costs that require outlays after revenues from business operations have ceased. This creates a high risk of "liability dumping" where assets are stripped from the firm, and end-of-life costs are shifted to taxpayers through bankruptcy or abandonment. Corporate actions such as structural separation, sales, or spinoffs may be used as tools to isolate lines of business with high liabilities from those that are more profitable. Large closure costs, radioactivity, and an extremely long period for which waste must be managed create more significant challenges for nuclear than most other sectors with AROs. Because the decommissioning costs are incurred at the end of a facility's lifetime, and LCOE calculations discount those costs (often over many decades), decommissioning appears to be immaterial to the sector's initial investment decisions. At a 10-percent cost of capital, for example, IEA estimates the cost of decommissioning for a newbuild plant at about US$0.01 per MWh, or a maximum (at a 3-percent cost of capital) still below US$0.40/MWh for all countries but the Slovak Republic.[1609] IEA's cost models suggest that an increase in decommissioning costs from 15 percent to 25 percent of total investment costs will raise generating costs by only 1 percent, and when accruals are collected throughout the full operation of the plant, the share of electricity prices is small.[1610]

Unfortunately, adequate funds are often not collected during the full operation of the facility. In other cases, collected funds have been misappropriated due to structural weaknesses in

1608 - MIT, "The Future of Nuclear Energy in a Carbon-Constrained World", 2018, op. cit., p. xviii.

1609 - IEA and OECD/NEA, "Projected Costs of Generating Electricity—2020 Edition", 2020, op. cit., pp.58–59.

1610 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.28.

controls. The near-disappearance of long-term liabilities in levelized cost models can create problems because the liabilities are hundreds of millions of dollars per reactor. Further, past experiences suggests that the prospective estimates are not great predictors of actual costs that will be incurred, and funding levels often lag far behind even the estimated costs on what will be needed. Decommissioning cost estimates for Advanced Gas-Cooled Reactors (AGRs) in the U.K. doubled between March 2004 and March 2021, to £$_{2021}$23.5 billion (US\$$_{2021}$32 billion or US\$$_{2023}$29.7 billion), and are at significant risk of rising further.[1611] A detailed reactor-level analysis estimated decommissioning costs for Germany, Italy, and Lithuania at €5.98 (US\$$_{2020}$6.82), €14.05 (US\$$_{2020}$16.02), and €13.78 (US\$$_{2020}$15.71) per MWh respectively for high-capacity commercial reactors—significantly larger than the IEA estimates and at a level that could affect the competitiveness of nuclear, especially on wholesale markets.[1612] Though countries have implemented a wide array of mechanisms to fund decommissioning costs (discussed below), in all cases taxpayers end up covering shortfalls, and these shortfalls can be very large.

Decommissioning programs need to effectively address a handful of core elements, each discussed in turn.

Who Must Cover the Cost?

In most countries, funding decommissioning is a legal obligation of the utilities.[1613] This structure aligns with the "polluter-pays" principle—built into the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management[1614]—which links the costs of addressing pollution to the products, services, and companies that generated it.

Despite this objective, however, decommissioning costs in many jurisdictions have been shifted in part or whole onto the state, creating a subsidy to nuclear. A recent IAEA review[1615] of decommissioning funding in 58 countries (covering fuel chain facilities and research reactors as well as power plants) indicated that although more than 60 percent of the countries officially rely only on user funding, many do not (see Table 23 hereunder). Twelve countries rely on government funding entirely for decommissioning and five are reliant on some government funding, due either to statutory structure or a shortfall in collected funds. For all groups, long-term shortfalls in funding are backstopped by governments, making funding adequacy of great importance and largely defeating the purpose and distorting the reality of nominal user funding.

1611 - Committee of Public Accounts, "Future of the Advanced Gas-cooled Reactors", HC118, House of Commons, 20 May 2022, see https://committees.parliament.uk/publications/22301/documents/165594/default/, accessed 27 November 2023.

1612 - Data provided by Alexander Wimmers via e-mail. A more detailed description of data is available upon request and can be found for Germany in Christian von Hirschhausen and Alexander Wimmers, "Rückbau von Kernkraftwerken und Entsorgung radioaktiver Abfälle in Deutschland: ordnungspolitischer Handlungsbedarf", *Perspektiven der Wirtschaftspolitik*, forthcoming (in German), see https://doi.org/10.1515/pwp-2023-0032, accessed 8 November 2023.

1613 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.28.

1614 - IAEA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management", adopted 5 September 1997, see https://www.iaea.org/topics/nuclear-safety-conventions/joint-convention-safety-spent-fuel-management-and-safety-radioactive-waste, accessed 30 November 2023.

1615 - IAEA, "Global Status of Decommissioning of Nuclear Installations", No. NW-T-2.16, IAEA Nuclear Energy Series, International Atomic Energy Agency, March 2023, see https://www-pub.iaea.org/MTCD/Publications/PDF/PUB2023_web.pdf, accessed 21 July 2023.

Table 23 · Funding Mechanisms for Decommissioning and Nuclear Waste Management

	Funding Management of Spent Fuel and High-level Radioactive Waste		Funding of Decommissioning	
Countries with Activities to be Funded	Number of Countries 47	Share of Countries	Number of Countries 49	Share of Countries
Funding Mechanisms				
Government Funding	10	21.3%	12	24.5%
Government Funding b/c State Owned Enterprise	4	8.5%	2	4.1%
Some Government Funding by Design or Shortfall	6	12.8%	5	10.2%
User Funding Only	27	57.4%	30	61.2%
All countries rely on governments to make up any shortfalls				

Sources: IAEA, 2023[1616]

What Funding Mechanisms and Investment Strategies are Employed?

Well-structured programs treat decommissioning as a sinking fund. Small collections, often per kWh, are invested so the accrued funds at the time of decommissioning will be adequate to the task. The investment phase is important because the decommissioning may occur many decades after the reactors have ceased operation. During that long period, investment returns need to offset inflation and cost escalation in decommissioning services, and ideally generate additional real returns to help cover costs and contingency allowances.

Under the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, liabilities begin as soon as the plant or fuel chain facility starts operation. Funds are often collected over the operating life of the facility, with investment growth helping to reach anticipated need. This makes sense, since after the reactor closes and no additional revenues flow in and the risks of contributions' ceasing rise. While not common, funding may continue after a reactor is closed, particularly in countries with large, centralized utilities that can contribute revenues from other plants to cover the nuclear liabilities, pooling the funds across a reactor fleet.

The sinking fund approach is similar to worker pension funds. As with pensions, the likelihood of having adequate funds to cover decommissioning depends on protecting the collected funds from other claims (such as corporate takeovers or bankruptcies) and fraud. Figure 60 below illustrates the most common approaches used, along with examples of which countries use them.

1616 - IAEA, "Global Status of Decommissioning of Nuclear Installations", No. NW-T-2.16, March 2023, op. cit., pp. 105–110.

Figure 60 · Structuring of National Decommissioning Funds

Decommissioning Fund Organization

<table>
<tr><th></th><th>Public Budget</th><th>Internal Segregated</th><th>Internal Non-Segregated</th><th>External Segregated</th><th>Guarantees</th></tr>
<tr><td>State Funded</td><td>U.K.
Germany</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Polluter-Pays Principle</td><td rowspan="2"></td><td rowspan="2">France
U.K.</td><td rowspan="2">Germany</td><td>U.K.
Switzerland
Sweden</td><td></td></tr>
<tr><td colspan="2">United States</td></tr>
</table>

Source: WIP/TU Berlin and DIW Berlin, 2023[1617]

In financially stable countries, public budget funding for decommissioning is the least likely to have shortfalls, though it provides a large ongoing subsidy to nuclear power. Public funding may also reduce the incentives to control costs that would exist in a privately-funded decommissioning effort.[1618] Further, publicly-provided decommissioning services often operate as a non-profit entity. In contrast, where non-nuclear energy resources are supplied by private firms, the tax-exempt status of decommissioning services creates an incremental competitive advantage for nuclear.

Internal funds are at greater risk of loss or misappropriation than external funds. For example, billions of £ allocated decommissioning funds for U.K. reactors were not properly segregated and were ultimately spent for other purposes.[1619] Thus the taxpayer had to chip in via government intervention. Formal internal segregation can somewhat reduce this risk.

External funds may be state-managed or independent. Specialized funds managed by the state are used in Sweden, Switzerland, and the U.K. The specialized nature of the funds improves expertise and helps protect accruals from misappropriation. However, the linkage between specific reactors, decommissioning closure costs, and power surcharges is weakened and cross-subsidies across reactors would be expected. This issue seems less likely to create conflicts in countries where much of the nuclear power plant capacity is state-owned (as in France, Sweden, and Switzerland) than it would in the United States where ownership is dispersed among not only different private firms but also public utilities with differing jurisdictions. An external, publicly-managed fund may also incorporate large operating subsidies, as funding can be sourced not only from fees on power consumers but from state transfers as well. For example, the U.K.'s Nuclear Liabilities Fund (which also handles waste) received nearly

1617 - DIW, "Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production", January 2023, p.18.

1618 - Christian von Hirschhausen and Alexander Wimmers, "Rückbau von Kernkraftwerken und Entsorgung radioaktiver Abfälle in Deutschland: ordnungspolitischer Handlungsbedarf", *Perspektiven der Wirtschaftspolitik*, forthcoming (in German), op. cit.

1619 - Steve Thomas, "Viewpoint: UK decommissioning funds: a cautionary tale", *Platts Power in Europe*, S&P Global, 5 June 2006; and Steve Thomas, "Final country report: United Kingdom", Public Services International Research Unit, University of Greenwich, in "Comparison Among Different Decommissioning Funds Methodologies for Nuclear Installations", edited by Wuppertal Institute for Climate, Environment and Energy, on behalf of the European Commission Directorate-General Energy and Transport, H2, 2007, see https://epub.wupperinst.org/frontdoor/deliver/index/docId/2598/file/2598_EUDecommFunds_UK.pdf, accessed 21 July 2023.

£10.7 billion (US$$_{2023}$13.5 billion) in state capital between June 2020 and March 2022,[1620] which is a subsidy to nuclear power, violating the polluter-pays principle.

In the U.S., protection for decommissioning assets arises through nuclear decommissioning trusts that are separate legal entities from the company owning or operating the reactor. Public reporting to regulatory authorities on an annual basis, as well as required audits by unrelated, independent firms, help ensure that funds are both adequate and protected prior to the start of decommissioning activities. This system evolved over time: through the late 1970s, there was usually no accrual for decommissioning at all. Internal trusts were allowed until 1988, after which external trusts were required to reduce the risk of "commingling and default".[1621] However, that system is now at risk, as discussed below.

How Much Funding Must Be Set Aside?

Decommissioning funding targets are set by statute or regulation, or by the utilities. Unfortunately, there remains quite limited empirical data on decommissioning: as of 2022, only 22 units out of more than 200 closed had been decommissioned. These were concentrated in only three countries: the U.S. (17 units); Germany (4), and Japan (1) (see Decommissioning Status Report). Of the decommissioned reactors, a scant 5 percent of the sites (11 reactors) have been returned to greenfield sites for unrestricted use. As a result, decommissioning estimates most often rely on engineering models, some based on studies done many decades ago. Underfunding of decommissioning reserves is a concern in many countries.[1622] These risks are exacerbated by core assumptions in the modelling, given that

> Small changes in the assumptions of the rates have tangible effects on the present value of the financial resources and hence the amount of funds that need to be set aside; in particular, when the rate of return (discount rate) is prone to overestimation and the cost escalation rate to underestimation.[1623]

Funding targets in the U.S. rely either on a regulatory minimum or a site-specific engineering estimate, both of which use cost models. These do a reasonable job estimating mean funding levels, but even with a 25-percent contingency margin, underfunding is common.[1624] Decommissioning cost estimates for U.S. reactors span a range of US$478–1,435/kWe for publicly-owned reactors and US$615–2,148/kWe for investor-owned reactors.[1625] The reasons behind the much higher cost projections for investor-owned utilities are not clear.

Detailed European case studies highlighted large aggregate shortfalls between provisioned funds for decommissioning and the expected costs. This gap amounted to estimated €10 billion

1620 - Nuclear Liabilities Fund Limited, "Annual Reports and Accounts 2023", 2023, p. 7

1621 - Doug Koplow, "B5: Other Federal Interventions Into Energy Markets", pp.10–11, in "Federal Energy Subsidies: Energy, Environmental and Fiscal Impacts—Report and Appendices", Energy Price and Tax Program, The Alliance to Save Energy, April 1993, B5-10–11, see https://www.earthtrack.net/sites/default/files/library/FedSubAppB5.pdf, accessed 22 July 2023.

1622 - Manon Besnard, Marcos Buser et al., "The World Nuclear Waste Report 2019", November 2019, op. cit., pp.79–83.

1623 - Ibidem, p. 78.

1624 - Rebecca Lordan-Perret, Rebekka Bärenbold et al., "An Ex-Ante Method to Verify Commercial U.S. Nuclear Power Plant Decommissioning Cost Estimates", WWZ Working Paper 2022/08, Center of Business and Economics, University of Basel, May 2022, pp. 2–3.

1625 - Callan Institute, "2022 Nuclear Decommissioning Funding Study", December 2022, pp. 5–6.

in France ($US\$_{2023}$10.9 billion), €6 billion in Germany ($US\$_{2023}$6.6 billion), and SEK29.7 billion ($US\$_{2023}$2.7 billion) in Sweden.[1626]

Provisioning estimates in E.U. countries generally refer to the projected cost of the service, not how much cash has already been set aside; thus, even if provisioning is not showing a shortfall against other estimates of expected need, there could still be funding gaps.

In France, several reports over the past decade have put into serious question the adequacy of decommissioning provisions. In 2015, independent financial analyst AlphaValue published a commercial report entitled "Électricité de France – What a mess!"[1627] It concluded:

- "EDF's dismantling costs are under provided by a factor of three on a 'private funding' basis per MW installed."
- "Based on today's levels, the German peers end up with more than €4bn [billion] per reactor by 2025 (€2.5bn current actuarial), while EDF may only have set aside €1bn for that rainy day. At current levels and discount rates, EDF would achieve the €4bn per reactor mark by … 2057 (…). This is 11 years behind their best case scenario: a 60-year reactor life."

A scathing 2017 "Information Report" of the French National Assembly on nuclear decommissioning[1628] basically confirmed the AlphaValue conclusions:

- "Decommissioning will take more time than anticipated. (…) The temptation will therefore be great for the utility to spread out the dismantling over time to compensate for the low level of provisions."
- "Provisions are among the lowest in the OECD, with no safety net in case of cost variances."
- Decommissioning cost "is underestimated if we include a number of elements that have not been taken into account" and because of "a discount rate of 4.4%, which was too optimistic."
- "Foreign dismantling operations are all more expensive."

Data on U.S. shortfalls reflect the gap between Nuclear Decommissioning Trust (NDT) balances (i.e., actually funded) and anticipated decommissioning costs. These exceed US$17 billion nationally, which the Callan Institute estimated translates to about US$1 billion per year in extra collections to fill the gap during the remaining operating license of the reactors.[1629] Outside of the U.S., much greater transparency on changes in provisioning estimates over time, and the portion of those estimates that have actually been funded, would be useful.

1626 - Alexander Wimmers, Rebekka Bärenbold et al., "Decommissioning of Nuclear Power Plants: Regulation, Financing , and Production", Data Documentation 104, Deutsches Institut für Wirtschaftsforschung/German Institute for Economic Research, WIP, University of Basel, Forschungsstelle für Nachhaltige Energie- und Wasserversorgung, January 2023, see https://www.diw.de/documents/publikationen/73/diw_01.c.864222.de/diw_datadoc_2023-104.pdf, accessed 21 July 2023.

1627 - Juan Camilo Rodriguez, "Electricité de France – What a mess!", AlphaValue, December 2015.

1628 - Julien Aubert and Barbara Romagnan, "Rapport d'information en conclusion des travaux d'une mission d'information relative à la faisabilité technique et financière du démantèlement des installations nucléaires de base", on behalf of the Commission for Sustainable Development and Spatial Planning, Assemblée Nationale/French National Assembly, 1 February 2017 (in French), see https://www.assemblee-nationale.fr/14/rap-info/i4428.asp#P1187_188935, accessed 6 September 2023.

1629 - Callan Institute, "2022 Nuclear Decommissioning Funding Study", December 2022, op. cit., pp. 5–6.

Ensuring Adequate Funds When Needed

Ensuring that decommissioning fund accrual meets financial needs involves preventing misallocation of collections (largely via the allowed fund structure and audit protocols), ensuring adequate collection of funds during the operating life of the facility, investing balances to earn appropriate returns, and carefully monitoring spending once decommissioning begins.

Allowed investment strategies vary by country. There is a tension between higher growth in invested assets (by including a large mix of higher return, but riskier and more volatile asset classes) and lower risk assets such as government bonds that face reduced default risks but may not grow sufficiently even to offset inflation. The U.S. originally restricted qualified decommissioning trust investments to low-risk Treasury and municipal bonds and bank deposits; this was relaxed in 1992 to facilitate higher returns.[1630] The U.K.'s Nuclear Liability Fund includes a cash portion that tends to have low returns and a Mixed Asset Portfolio that aims for higher returns to help defray the cost of decommissioning to taxpayers.[1631] Over the next few decades, markets will belatedly test the wisdom of these choices.

License Transfers to Specialized Decommissioning Firms: Financial and Incentive Risks

Because decommissioning costs are so uncertain, even accruing the target amount of funding will not necessarily be sufficient to cover the actual costs incurred. In this context, the rise of specialized decommissioning firms across the U.S. needs to be monitored carefully. In recent years, a growing number of closed nuclear reactors have transferred their operating licenses to subsidiaries or joint ventures of North Star, Holtec, or EnergySolutions.

Corporate subsidiaries have been created to assume ownership of the closed reactors, including site assets and liabilities. Under the license stewardship approach, and assuming that sites are properly managed, licenses would be transferred back to the utility at the end of decommissioning. Under a license acquisition approach, the decommissioning firm would take over the plant including responsibility for spent fuel and rights to develop the site post-decommissioning.[1632] Critically, the new firm assumes responsibility for decommissioning and site remediation, while also gaining access to the accrued funds in the Nuclear Decommissioning Trust (NDT).

The firms argue that as specialized providers of decommissioning and nuclear waste transport and storage services, they can properly close the plants far more quickly, and for a lower cost, than the original owners could. They advertise benefits to the local community by bringing much of the site back into productive use sooner, and to the utility owners by capping and ending the utility's long-term exposure to a task they were not well-equipped to do themselves.

1630 - Doug Koplow, "B5: Other Federal Interventions Into Energy Markets", p.11, in "Federal Energy Subsidies: Energy, Environmental and Fiscal Impacts—Report and Appendices", Energy Price and Tax Program, The Alliance to Save Energy, April 1993, B5-11, op. cit.

1631 - DIW, "Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production", January 2023, op. cit.

1632 - Alexander Wimmers and Christian von Hirschhausen, "Supplement of Lessons for the organization of nuclear decommissioning from the UK and the US: risks, challenges, and opportunities", Workgroup for Infrastrucure, Technical University of Berlin, and German Institute for Economic Research, 14 September 2023, published as supplement to publishings of the research symposium "Safety of Nuclear Waste Disposal", German Federal Office for the Safety of Nuclear Waste Management, 13–15 September 2023, see https://doi.org/10.5194/sand-2-7-2023-supplement, accessed 7 November 2023.

However, this approach also contains potentially important structural problems. For example, where prior owners often were well-capitalized utility companies, the new approach enables them to wash their hands of their now-unproductive reactor; the new owner is an asset-free, standalone Limited Liability Company (LLC). Further, the independent NDT (the main source of funds for this work) becomes the piggy-bank to pay the new owner, even though decisions by this new owner influence the scope of the work, and the entity is often using related-party subsidiaries and products to carry out those decisions.

Finally, oversight roles and powers may not be sufficiently defined to prevent poorly done cleanups, cut corners, or an unfinished job when the trust funds run out. Investors in this space have included private equity firms, a segment known for having very high target returns on investment and limited asset holding periods. Energy Solutions is majority owned by TriArtisan Capital Advisors, a private equity firm that has also owned stakes in restaurants TGI Friday and P.F. Chang's.[1633] J. F. Lehman, a private equity fund, acquired NorthStar Group Services in 2017, established a partnership with Orano (called Accelerated Decommissioning Partners), and acquired Waste Control Specialists in 2018 to form the North Star Group. The ability to be compensated for multiple parts of the decommissioning process was a draw—or, according to Scott State, CEO of NorthStar and Waste Control Specialists:

> The deals allow Lehman's companies to save money at every step of decommissioning… We own and control everything we need to do this work. [1634]

A central concern on funding adequacy for the privatization models is the risk of discovering more, or worse, pockets of contamination than had been expected and budgeted for, resulting in fund shortfalls.[1635] Indeed, shortfalls are anticipated in the decommissioning fund for the Palisades plant.[1636] Other areas of conflict have started to emerge as well. The Pilgrim reactor in Massachusetts is being decommissioned by Holtec. The firm has pushed to discharge radioactive water into nearby Cape Cod Bay, an important marine ecosystem; as this approach would be less expensive than shipping it to an authorized disposal site.[1637] Holtec has been trying to do the same with radioactive water from the Indian Point Nuclear Power Plant into the Hudson River, in the State of New York.[1638] A review of regulatory reports at multiple decommissioning sites by *The Washington Post* found a reliance on contractors rather than better-trained staff, elimination of emergency planning measures, and more violations at the Oyster Creek Site (managed by Holtec) during the three years they had owned it than over the

1633 - Douglas MacMillan, "The dangerous business of dismantling America's aging nuclear plants", *The Washington Post*, 13 May 2022, see https://www.washingtonpost.com/business/2022/05/13/holtec-oyster-creek-nuclear-plant-cleanup/; and Energy Solutions, "Acquisition of EnergySolutions by TriArtisan Capital Advisors Closed", Press Release, 16 May 2022, see https://www.energysolutions.com/acquisition-of-energysolutions-by-triartisan-capital-advisors-closed/; both accessed 21 July 2023.

1634 - Christopher Maag, "Investors see huge profits from old nuclear plants, but it could cost taxpayers", *NorthJersey.com*, 19 June 2019, see https://eu.northjersey.com/story/news/watchdog/2019/06/19/nuclear-plant-decommissioning-holtec-other-firms-see-profit/1456809001/, accessed 21 July 2023.

1635 - Ibidem.

1636 - *The Washington Post*, "The dangerous business of dismantling America's aging nuclear plants", 13 May 2022, op. cit.

1637 - Heather McCarron, "APCC urges Healey to enforce Ocean Sanctuaries Act to block Holtec dumping", *Cape Cod Times*, 14 April 2023, see https://eu.capecodtimes.com/story/news/environment/2023/04/14/apcc-protests-holtec-radioactive-water-discharge-plan/70109798007/, accessed 21 July 2023.

1638 - Patrick McGeehan, "Plan for Dumping Nuclear Wastewater Into Hudson River Is Paused", *The New York Times*, 14 April 2023, see https://www.nytimes.com/2023/04/14/nyregion/hudson-river-nuclear-waste.html, accessed 8 August 2023.

prior ten years of utility ownership.[1639] There are also potential concerns over the use of NDT funds for non-approved uses. On its Indian Point decommissioning efforts, Holtec sought "an exemption from the Commission [U.S. Nuclear Regulatory Commission] to use NDT funds to finance activities related to spent fuel management and site restoration activities, both of which are beyond the scope of the stated purpose of each master trust…."[1640]

In the face of a cost overrun in decommissioning, a bankruptcy of the privatized, site-specific decommissioning firm, or an accident, there would be insufficient funds to address the decommissioning requirements of the plant. Lordan-Perrett et al. evaluated options to backfill cash in this type of event.[1641] Reaching up to better capitalized corporate parents, either at the decommissioning firm or the original utility that had owned the nuclear power plant, would require "piercing the corporate veil" but the authors found successful applications of these approaches to be both rare and narrow. Further, historical court cases have laid out a framework for parent companies to follow, to avoid being swept in. At the very least, the authors anticipate a long and hard-fought legal battle before any resources to cover shortfalls could be sought and assembled. Attempts to tap into joint-and-several liability provisions of the Comprehensive Environmental Compensation Liability Act (CERCLA)—the U.S. statute governing liability for hazardous waste—would be equally challenging and also require long and expensive litigation. These authors estimate that accidents would be funded first from private insurance, then the Price-Anderson fund from plant owners (a cost socialized to all nuclear operators), but if costs were significantly high, it would require additional public funding.[1642]

State Support to Finance and Deliver Nuclear Waste-Management Services

Management of nuclear waste shares many of the challenging economic attributes of decommissioning liabilities. One is the scale of the task. While other industries also have wastes, the technical requirements for nuclear waste are bigger, more expensive, and extend over a much longer period. The costs of managing these wastes also follow the polluter-pays principle, in that funding is supposed to come from the operator during the facility's lifetime. And as with decommissioning (though even more so), the costs are so uncertain that estimating the funding needed is challenging to do with any accuracy. Another similarity: with repository opening dates so far into the future, LCOE models tend to discount away the needed accruals, thereby minimizing the impact of this complex problem on current economic decisions and selected energy pathways. Nuclear waste funds also require careful segregation and management to ensure they are available to achieve the purpose for which they were

1639 - *The Washington Post*, "The dangerous business of dismantling America's aging nuclear plants", 13 May 2022, op. cit.

1640 - Chiara Trabucci, "Declaration before the Secretary of the Nuclear Regulatory Commission in the Matter of Indian Point Nuclear Generating Station", Industrial Economics Incorporated, Before the United States Nuclear Regulatory Commission, 7 February 2020, p. 13, see https://www.nrc.gov/docs/ML2004/ML20043E128.pdf, accessed 23 August 2023.

1641 - Rebecca Lordan-Perret, Robert D. Sloan and Robert Rosner, "Decommissioning the U.S. nuclear fleet: Financial assurance, corporate structures, and bankruptcy", University of Basel, Tulale University Law School, and University of Chicago, published in *Energy Policy*, Vol. 154, July 2021, see https://doi.org/10.1016/j.enpol.2021.112280, accessed 21 July 2023.

1642 - Ibidem, p.6.

collected. Funds are generally supposed to be ring-fenced to prevent diversion, though this has not always happened in practice.[1643]

The fission process yields spent fuel that is often managed on site while its radioactivity decays (close to half of spent fuel worldwide is currently stored onsite);[1644] low- and intermediate-level radioactive waste, for which there are some existing repositories; and high-level radioactive waste, the focus of this section. Government policies that pay most, or all, of the cost of managing nuclear waste create a subsidy for nuclear power. This comes partly through the repository contributions that were not charged to nuclear power plant owners and customers as they should have been. Importantly, however, the long-tail risk from the uncertainty and high potential costs of dealing with the waste would, by itself, chill investor excitement about the sector and confidence in the predictability of returns. This would be reflected in a higher cost or reduced availability of capital. At least as far back as 1980, it was recognized that "[g] overnment responsibility for ultimate waste disposal removes significant uncertainties from those investing in nuclear power production."[1645] The simple willingness by governments the world over to take legal responsibility for the waste constitutes a very large subsidy to the sector.

Jigar Shah, the director of the Office of Loan Programs at the U.S. Department of Energy, heads one of the largest pools of publicly-sourced investment capital in the world focused on decarbonization-related investments. Overall, the lending capacity exceeds US$400 billion, including significant allocations to nuclear reactors and other parts of the fuel chain.[1646] He seems unconcerned about the challenges of nuclear waste, writing in a LinkedIn post in June 2023 that:

> Nuclear waste is interesting in how it is discussed. Nuclear waste decays exponentially, so the "radioactive" part decays away in the first few years, stored and monitored safety [sic] onsite at a nuclear plant. Then what is remaining is very long-lived isotopes a [sic] which are barely radioactive. The totally [sic] volume is small. Nuclear waste needs to be handled with care but we frankly should be far more worried about coal fly ash and other energy waste streams much more.[1647]

The post was edited about a month later to correct typos, and to change "barely radioactive" to "less radioactive", though the overall tenor remained. Others, including plant owners, operators, and regulators, seem not to agree that nuclear waste is simple. Across the world, progress has been slow and industry and legislative efforts have increasingly shifted responsibility for this costly, long-lived activity to the public sector.

Strategies for waste management via reprocessing and reuse have been expensive and of concern especially in terms of proliferation risks involving large quantities of weapons-usable

1643 - OECD/NEA, "The Economics of the Back End of the Nuclear Fuel Cycle", Nuclear Energy Agency, Revised 23 October 2013, p. 59, see https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/7061-ebenfc.pdf, accessed 17 July 2023.

1644 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.27.

1645 - Joseph Bowring, "Federal subsidies to nuclear power: Reactor design and the fuel cycle", Pre-publication draft, Financial and Industry Analysis Divison, Office of Economic Affairs, U.S. Energy Information Administration, 1980, see https://www.earthtrack.net/sites/default/files/EIA%20Nuclear%20Subsidies%201980.pdf, accessed 23 August 2023.

1646 - Holland & Knight, "DOE Loan Programs Office: 2023 Updates, Overview and Key Insights", 1 February 2023, see https://www.hklaw.com/en/insights/publications/2023/02/doe-loan-programs-office-2023-updates-overview-and-key-insights, accessed 21 July 2023.

1647 - Jigar Shah, LinkedIn post, June 2023, see https://www.linkedin.com/posts/jigarshahdc_finlands-plan-to-bury-spent-nuclear-fuel-activity-7074820419391770625--yEh, accessed 14 June 2023 and 11 August 2023.

materials (plutonium). Most countries are focused instead on deep geological repositories, and while more than half of the countries plan to fund these costs only through fees on generators (see Table 24), a great deal of residual risk and cost remains with taxpayers:

> The construction of the deep repository for radioactive waste has suffered a considerable delay. There is no sufficient worldwide reference for the planned concept.
>
> As a result, the true cost will only be known decades after the last nuclear power plant has been decommissioned – at a point when the owners will most likely have ceased to exist in their present form. The owners will therefore not be able to make any additional payments.[1648]

This risk is compounded by the enormous scale of anticipated costs. Estimates for the United States reach as high as US$_{2018}$\$168 billion;[1649] for the French high-level waste repository construction, there is a target cost of €$_{2016}$25 billion (US\$$_{2016}$28 billion).[1650] For Canada, the estimate is CAD26 billion (US\$$_{2020}$19.4 billion);[1651] when including all radioactive waste streams, estimated disposal costs reach €149 billion (US\$$_{2023}$163 billion) in Germany;[1652] and roughly CHF$_{2021}$19.4 billion (US\$$_{2021}$21.2 billion) for Switzerland.[1653] While these figures are not all estimating exactly the same services over the same timeframe, it is clear the repositories are expensive, and based on escalation patterns for projects of this scale, costs seem likely to rise.

Table 24 provides an overview of geological repository progress in key countries. State ownership and management predominate. Even where some of the countries assign responsibility to utilities (such as with Sweden and Finland), the utilities responsible for building and managing the repository, through a multi-utility partnership, are themselves largely state-owned. While the challenge of constructing deep geological storage has been known for decades, delivery of a viable option continues to be kicked further into the future nearly everywhere. Many countries still have not set timelines for repository completion, have pushed forward previously-set targets, or have set deadlines decades into the future.

Interestingly, the push for Small Modular Reactors (SMRs) may exacerbate the nuclear waste management challenge. Thorium-232/uranium-233 fuel chains will not produce less radioactive

1648 - Alexander Budzier, Bent Flyvbjerg, Andi Garavaglia, and Andreas Leed, "Quantitative Cost and Schedule Risk Analysis of Nuclear Waste Storage", Oxford Global Projects, Saïd Business School, University of Oxford, 10 December 2018, published 3 January 2019, p.4, see https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3303410, accessed 21 July 2023.

1649 - GAO, "Commercial Spent Nuclear Fuel—Congressional Action Needed to Break Impasse and Develop a Permanent Disposal Solution", GAO-21-603, Report to Congressional Addressees, United States Government Accountability Office, September 2021, p.34, see https://www.gao.gov/assets/gao-21-603.pdf, accessed 21 July 2023.

1650 - Andra, "The Cigeo Project—France's Industrial Centre for Geological Disposal of radioactive waste", Agence Nationale pour la Gestion des Déchets Radioactifs/National Agency for the Management of Nuclear Waste, May 2020, see https://international.andra.fr/sites/international/files/2021-11/Andra-Plaquette_Cigeo-MAJ-19_08-ALR_CO2_V2_EN.pdf; and Gilbert Reilhac and Lucien Libert, "Quiet no more, French village becomes center of anti-nuclear protest", *Reuters*, 18 April 2018, see https://www.reuters.com/article/us-france-nuclearpower-waste/quiet-no-more-french-village-becomes-center-of-anti-nuclear-protest-idUSKBN1HP1SC; both accessed 21 July 2023.

1651 - Estimate for 2021 in CAN\$2020; see Nuclear Waste Management Organisation, "APM 2021 DGR Lifecycle Cost Estimate Update Cost Summary Report", September 2021, p. iv, see https://www.nwmo.ca/-/media/Reports-MASTER/Funding-and-project-costs/NWMOTR202111-APM-2021-DGR-Lifecycle-Cost-Estimate-Update.ashx, accessed 21 November 2023.

1652 - Calculation from DIW, "Decommissioning of Nuclear Power Plants: Regulation, Financing, and Production", January 2023, op. cit., based on Klein & Warth Grant Thornton, "Gutachtliche Stellungnahme zur Bewertung der Rückstellungen im Kernenergiebereich", commissioned by the Federal Ministry of Economy and Energy, Federal Government of Germany, 9 October 2015, see https://www.bmwk.de/Redaktion/DE/Downloads/S-T/stresstestkernenergie.pdf?__blob=publicationFile&v=3, accessed 22 July 2023.

1653 - Nagra, "Waste Management Programme 2021 of the Waste Producers", Technical Report 21-01E, Nationale Genossenschaft für die Lagerung radioaktiver Abfälle/National Cooperative for the Disposal of Radioactive Waste, December 2021.

waste than uranium fuels as is commonly perceived.[1654] Some designs appear to produce more waste than standard reactors. Analysis of three distinct SMR designs, for example, found that "relative to a gigawatt-scale PWR, these reactors will increase the energy-equivalent volumes of SNF [Spent Nuclear Fuel], long-lived LILW [Low- and Intermediate-Level Waste], and short-lived LILW by factors of up to 5.5, 30, and 35, respectively. These findings stand in contrast to the waste reduction benefits that advocates have claimed for advanced nuclear technologies."[1655]

The analysis, carried out by a group of researchers from several universities, including Allison MacFarlane, former Chair of the U.S. Nuclear Regulatory Commission (NRC), also found that

> SMR waste streams will bear significant (radio-)chemical differences from those of existing reactors. Molten salt– and sodium-cooled SMRs will use highly corrosive and pyrophoric fuels and coolants that, following irradiation, will become highly radioactive. Relatively high concentrations of ^{239}Pu and ^{235}U in low–burnup SMR SNF will render recriticality a significant risk for these chemically unstable waste streams.[1656]

To the extent that SMR-specific waste streams drive up costs for waste management either on-site or eventually at repositories, activity-based costing would recover the full amount of these increases via higher waste fees on those SMR reactors. These costs should be reflected in SMR LCOEs as well.

Missing Nuclear Waste Fee Collections Has a High Cost: U.S. Case Study

The U.S. provides a useful case study of the problems that arise from improper incentive alignment for a complex challenge like nuclear waste management. Despite the technical and political complexity of siting, building, and operating a geological repository for spent nuclear fuel, the Nuclear Waste Policy Act of 1982 required the federal government to do so in a given timeframe.[1657] The "standard contract" offered to utilities assigned all responsibility for building and managing the waste repository to the U.S. government via the U.S. Department of Energy. Also included was the cost to move the waste from the reactor to the repository.[1658] Shifting of so much risk onto the government party differs markedly from how other endeavors with high cost and delivery uncertainty share risks and rewards. For example, around 2008 there was a surge of interest in building new reactors:

1654 - NASEM, "Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors", National Academies of Sciences, Engineering, and Medicine, 2023 p.55, see https://nap.nationalacademies.org/catalog/26500/merits-and-viability-of-different-nuclear-fuel-cycles-and-technology-options-and-the-waste-aspects-of-advanced-nuclear-reactors, accessed 21 July 2023.

1655 - Lindsay M. Krall, Allison M. Macfarlane and Rodney C. Ewing, "Nuclear waste from small modular reactors", Center for International Security and Cooperation, Stanford University, and School of Public Policy and Global Affairs, Univeristy of British Columbia, published in *PNAS*, 31 May 2022, see https://www.pnas.org/doi/10.1073/pnas.2111833119, accessed 27 November 2023.

1656 - Ibidem.

1657 - Kim Cawley, "The Federal Government's Responsibilities and Liabilities Under the Nuclear Waste Policy Act", Testimony before the Subcommittee on Environment and the Economy Committee on Energy and Commerce, Congressional Budget Office, U.S. House of Representatives, Congress of the United States, 3 December 2015, p.2, see https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51035-NuclearWaste_Testimony.pdf, accessed 21 July 2023.

1658 - GAO, "Commercial Spent Nuclear Fuel—Congressional Action Needed to Break Impasse and Develop a Permanent Disposal Solution", GAO-21-603, Report to Congressional Addressees, United States Government Accountability Office, September 2021, p.19, see https://www.gao.gov/assets/gao-21-603.pdf, accessed 21 July 2023.

> Securing rights to purchase heavy reactor forgings from Japan Steel Works required deposits estimated at $100 million, which were needed to reserve limited forging capacity for an ultimate purchase worth $300 million to $350 million. The effective reserve rate was 28 to 33 percent of the total forging cost.[1659]

In contrast, the standard contract for U.S. nuclear power plants also set a date certain of 31 January 1998 by which its never-before-built facility would "begin taking possession of and responsibility for spent nuclear fuel from nuclear power plants nationwide."[1660] These unbounded costs were to be funded via a US$0.001/kWh charge on nuclear-generated electricity, with proceeds fed into a Nuclear Waste Trust Fund for safekeeping. While the fee could be increased if collected funds were inadequate, the facility operating life exceeds reactor life by a large margin, limiting the ability to fund mid-course corrections. However, the Nuclear Waste Fund Policy Act transformed this long-lasting and uncertain liability associated with managing nuclear waste was transformed into an immaterial fixed charge on generated power.

Over many years, substantial funds from the Trust were spent on a permanent repository at Yucca Mountain in Nevada. This was eventually blocked in court. When the federal government failed to deliver a waste repository by the 1998 deadline, utilities sued for breach of contract. They won, and as a result, taxpayers are paying utilities to continue storing their waste fuel onsite. These payments are not authorized to come out of the Trust Fund, so they are being directly paid by taxpayers via a Judgement Fund. The liability from this breach is estimated at over US$10 billion already paid to utilities plus residual liabilities of around US$31 billion as of September 2022, which will rise if delays continue.[1661] These costs are all in addition to the cost of actually building and operating the repository and require no Congressional appropriation before being paid to utilities.

Further, courts ruled that the government could not continue to surcharge nuclear-generated electricity for the Trust Fund as, with no specific repository approved, there was no way for the government to estimate the needed funding with any precision—a requirement to set and levy the fees. At first glance, this seems not a problem since the fund held a balance of US$46 billion as of September 2022, and continues to grow over time from compounded interest.[1662]

1659 - Yoshifumi Takemoto and Alan Katz, " Samurai-sword maker's reactor monopoly may cool nuclear revival", *Bloomberg*, 12 March 2008, see https://www.bloomberg.com/news/articles/2008-03-12/samurai-sword-maker-s-reactor-monopoly-may-cool-nuclear-revival, accessed 7 September 2023.

1660 - *Nuclear Newsswire* "A fateful day for nuclear waste policy: January 31, 1998", American Nuclear Society, 26 January 2023, see https://www.ans.org/news/article-4695/a-fateful-day-for-nuclear-waste-policy-january-31-1998/, accessed 10 August 2023.

1661 - Office of Cyber Assessments and Data Analytics, "The Department of Energy Nuclear Waste Fund's Fiscal Year 2022 Financial Statement Audit", Audit Report DOE-OIG-23-05, Office of Inspector General, Department of Energy, U.S. Federal Government, November 2022, p.26–27, see https://www.oversight.gov/sites/default/files/oig-reports/DOE/DOE-OIG-23-05.pdf, accessed 22 July 2023.

1662 -Ibidem, p.10.

Table 24 · Nuclear Waste Repository Planning and Ownership (by Country)

Country	Share of Global Once Operating Nuclear Capacity*	Disposal Site Location	Status	Commissioning date as of 2023	Repository Ownership as of 2023
United States	23.32%	None selected to replace Yucca Mountain	Project proposed	Suspended	State
France	13.48%	Cigéo	Site selected	2035 (10-year slippage from 2015 estimate)	State
China	10.71%	None selected	Project proposed	2050+	State
Japan	9.83%	None selected	Project proposed	2035	Utility
Russia	6.38%	Krasnoyarsk	Site selected	To be confirmed	State
Germany	5.31%	None selected	Site search	2046–2068+ for site selection (several decades slippage from 2015 estimate)	State
South Korea	5.18%		Under study	Construction of underground facilities from 2043-2060	State
Canada	3.17%	None selected	Project proposed	2040+ (5-year slippage from 2015 estimate)	Mixed; NWMO set up by utilities (some state-owned) and Atomic Energy Canada LTD.); not clear on ownership of the repository site.
United Kingdom	2.75%	None selected	Project proposed	2040 (was no target date in 2015)	State
Sweden	2.21%	Forsmark	Site selected	2030-2032 (2-4-year slippage from 2015 estimate)	Mixed; utility responsibility, though most of the reactors are owned by Vattenfall AB which is wholly owned by the Swedish state.
Spain	1.65%				State
India	1.39%	None selected	Project proposed	To be confirmed	State
Belgium	1.2%				State
Finland	0.88%	Onkalo	Construction underway	2024	Mixed; Posiva owned by Fortum (majority state-owned) and TVO (private, but partially owned by Fortum)
Czech Republic	0.79%	None selected	Project proposed	2065	State
Switzerland	0.67%	Nördlich Lägern	Site selected	2060 (was no target date in 2015)	State
Slovakia	0.65%	None selected	Project proposed	To be confirmed	
Hungary	0.39%	None selected	Project proposed	2030	State

Sources: compiled by WNISR, based on NEA, 2020; WNA, 2023; IAEA/PRIS, 2023; repository owner websites, 2023; Pulse, 2022[1663]

Note: * Share of global capacity based on Operating, LTO and Closed reactors as of 1 July 2023.

Unfortunately, the repository will probably cost substantially more. Based on the original location at Yucca Mountain, Sandia National Laboratory had last completed a cost estimate for

1663 - NEA, "Management and Disposal of High-Level Radioactive Waste: Global Progress and Solutions", NEA No. 7532, Nuclear Energy Agency, Organisation for Economic Co-operation and Development, 2020, p.41, see https://www.oecd-nea.org/jcms/pl_32567/management-and-disposal-of-high-level-radioactive-waste-global-progress-and-solutions?details=true; and WNA, "Storage and Disposal of Radioactive Waste", World Nuclear Association, January 2023, see https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste.aspx; also *Pulse*, "Korea to earmark $1.1 bn to develop high-level nuclear waste management", 21 July 2022, see https://pulsenews.co.kr/view.php?year=2022&no=642934; all accessed 17 July 2023; and repository owner websites.

a U.S. repository in 2019, with projected costs of US$75–119 billion. Absent a legislative change in the nuclear waste fee, these excess costs will probably flow to taxpayers.[1664] Of this, most will be a subsidy to nuclear power, since more than 85 percent of the tonnage for geological disposal is from commercial reactors rather than military activities.[1665] Including the Judgement Fund payments and costs paid out from other resources, the total costs of managing wastes "range from about US$102–139 billion in the 2031 disposal scenario, and from about US$141–168 billion in the 2117 disposal scenario".[1666]

Given the large gap between current balances and expected costs, the cost of suspension of the Nuclear Waste Fee becomes clear, particularly since the reactors have a finite operating life and lost collection years cannot be replaced later. The dollars lost are large: since the suspension of the fund in May 2014 through the end of 2022, US$6.8 billion in fees on nuclear-generated electricity have not been collected based on WNISR calculations, and compounded returns that would have been earned on those funds through as late as 2117 are also lost. At a 3 percent real return, waste fees during this period would have compounded to more than US$125 billion by 2117.

Insufficient Liability Coverage for Nuclear Accidents

Insurance helps to protect individuals and businesses against catastrophic losses. The cost of insurance premia signals which activities are riskier, and where investments in improved training, safety equipment, or improved products could reduce insurance costs while also providing improved safety for workers and customers. Because not every energy pathway entails the same risks to people, property, and the environment, accurate insurance premia can incentivize shifts to lower-risk options, including for nuclear plant safety. Where government rules allow some firms and activities to operate with insufficient insurance limits to realistically address damages they can cause others, this constitutes an operating subsidy.

Inadequate or subsidized insurance to cover offsite damages from accidents at nuclear plants or fuel chain facilities, or during transportation, is common worldwide. Focusing on reactor accidents as an example, liability requirements for offsite damages are set by domestic statute. Additional tiers may be provided by national governments once the operator liability limit is reached; and then by a third tier of coverage provided by series of international treaty agreements (which include the Paris Convention, Vienna Convention, various Joint Protocols and Supplementary Conventions). The treaties help to set a coverage floor, and to standardize coverage somewhat across very diverse countries. However, even the total coverage in the U.S., which is the largest liability pool in the world for nuclear accidents, is well below expected damages from even a moderate accident. For example, the Japanese Government estimated the cost of the 2011 Fukushima accidents at US$$_{2021}$223 billion, more than sixteen times the total U.S. insurance pool of US$13.6 billion. In 2019, an independent assessment by the Japan Center for Economic Research (JCER) came up with a cost range of US$$_{2021}$322–758 billion,

1664 - GAO, "Commercial Spent Nuclear Fuel—Congressional Action Needed to Break Impasse and Develop a Permanent Disposal Solution", GAO-21-603, 2021, op. cit., p. 34.

1665 - Ibidem, p.1.

1666 - Ibidem, p.34.

with the higher end including US$$_{2021}$370 billion for tritium removal.[1667] This range represents 23–56 times the total U.S. nuclear insurance pool.

Operator coverage is sometimes paid for by the state, and while this structure is helpful to protect parties who may be harmed in an accident, it results in larger subsidies to the operator and weak price signals to invest in safety-enhancing upgrades and training.

OECD's Nuclear Energy Agency (NEA) data indicate that Germany, Japan, and Russia have instituted unlimited liability on operators.[1668] Finland has unlimited operator liability for damages inside the country only; and Sweden provides it internally and to selected neighboring countries as well. Unlimited coverage in countries where state ownership dominates is little different from a state guarantee, and in other nations will still be limited by firm bankruptcy, as occurred with TEPCO in Japan following 3/11. However, where risks are not socialized, it is clear that insurance does affect market behavior. A major deterrent to foreign reactor supply to India's nuclear program is India's Civil Nuclear Liability law, passed in 2010. By including liability on the equipment provider and builder, foreign suppliers have steered clear of the sector.[1669]

Table 25 summarizes liability coverage in US$ that applies to the largest countries by nuclear generating capacity. Most countries have less than US$3 billion in coverage from all sources, and some important nuclear power countries appear to have significantly lower liability capacity. This includes the equivalent of only US$640 million per accident in India, US$340 million in South Korea, less than US$50 million in China.

The U.S. liability system has three liability tiers for operators. The first requires a plant-specific policy for damages up to US$450 million—a lower coverage amount on an inflation-adjusted basis than in 1960.[1670] This is despite enormous growth in population and real estate values surrounding reactors during this period, and much more actuarial data that should have stimulated higher coverage. The second tier uses retrospective premia of about US$131 million charged to every reactor if there is an accident with damages exceeding the individual coverage at any reactor. These retrospective premia provide the bulk of the coverage, and if there is still need after this total pool is exhausted, there is an option for a 5 percent surcharge on all reactors that boosts the total pool by roughly another US$625 million. This shared risk approach provides a stronger industry-wide incentive to police safety, and a larger compensation pool that is ostensibly independent of government support. The size of the pool declines as older reactors close. Should a shift to SMRs occur, protections under the Price-Anderson Act will also suffer. Smaller reactors such as SMRs have much lower primary limit requirements via the mandated purchase of a reactor-specific insurance policy. These depend on the size of the

1667 - See Fukushima Status Report in WNISR2021 for detailed assumptions and references, see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor084, accessed 16 October 2023.

1668 - OECD/NEA, "Nuclear Operators' Third Party Liability Amounts and Financial Security Limits", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, Updated June 2022, see https://www.oecd-nea.org/upload/docs/application/pdf/2022-06/2020.10_operators_liability_amount_table_general_final_clean_v2_2022-06-30_13-34-34_716.pdf, accessed 21 July 2023.

1669 - Indrani Bagchi, "India needs to take a harder look at its nuclear liability law", *The Times of India*, 7 November 2021, see https://timesofindia.indiatimes.com/blogs/globespotting/india-needs-to-take-a-harder-look-at-its-nuclear-liability-law/, accessed 7 November 2022.

1670 - U.S. NRC, "The Price-Anderson Act: 2021 Report to Congress", NUREG/CR-7293, U.S. Nuclear Regulatory Commission, December 2021, p. 1-12, see https://www.nrc.gov/docs/ML2133/ML21335A064.pdf, accessed 4 August 2023.

reactor but cover a damage range of only US$4.5–74 million. Further, if the reactors are smaller than 100 Mwe, they need not participate in the retrospective premium pool at all.[1671]

Unfortunately, the U.S. scheme has some important limitations even for larger reactors. The retrospective premiums are paid in over multiple years, reducing the net present value of the coverage and separating the timing of the incoming cash flows from the acute damage period when funds will be most needed. Further, the premium can be waived if the industry is under economic duress. For firms owning many reactors, the retrospective premia can add up to very large annual payments, probably coming due at the same time as they need to invest in safety retrofits as often occurs following any major nuclear accident.[1672] If the accident caused still-operating reactors to be closed, as in Japan after 3/11, then their owners would earn less revenue and pay for costly replacement power, weakening their financial position. The share of U.S. generating capacity owned by the 12 largest nuclear holding companies increased from 54 percent in 1999 to 77 percent in 2019.[1673] This combination concentrates risk and may increase the likelihood of a waiver or defaults. The Price-Anderson Act also makes the federal government the *de facto* guarantor for unpaid assessments on the first two tiers under 42 U.S. Code § 2210(b)(3):

> The Commission shall establish such requirements as are necessary to assure availability of funds to meet any assessment of deferred premiums within a reasonable time when due, and may provide reinsurance or shall otherwise guarantee the payment of such premiums in the event it appears that the amount of such premiums will not be available on a timely basis through the resources of private industry and insurance.

While the government can try to reclaim these costs later, the likelihood of that happening following this type of payment default is fairly low. In effect, the government provides more than US$13 billion in reinsurance coverage to commercial operators for free. In contrast, American Nuclear Insurers (ANI), the industry's mutual carrier, will cover a maximum of US$60 million for defaulted payments by its members, about 0.5 percent as much.[1674] While premia do not move linearly, given that the average ANI premium per reactor for primary insurance of more than US$400 million in 2019 was only about US$1 million,[1675] increasing the private sector coverage for retrospective payment defaults after an accident would seem doable.

To allow for adjustments in light of changing market conditions, the Price-Anderson Act periodically expires and must be renewed by Congress (though coverage for the existing fleet

1671 - Ibidem, pp. 3-8, 3-9.

1672 - Doug Koplow, "Nuclear Power: Still Not Viable without Subsidies", Earth Track, Inc., published by Union of Concerned Scientists, February 2011, pp.78–83, see https://www.earthtrack.net/sites/default/files/uploaded_files/nuclear%20subsidies_report.pdf, accessed 21 July 2023.

1673 - U.S. NRC, "The Price-Anderson Act: 2021 Report to Congress", NUREG/CR-7293, United States Nuclear Regulatory Commission, December 2021, p.2–10, see https://www.nrc.gov/docs/ML2133/ML21335A064.pdf, accessed 4 August 2023.

1674 - Ibidem, p. 2-63.

1675 - WNA,"Liability for Nuclear Damage", World Nuclear Association, March 2021, see https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/liability-for-nuclear-damage.aspx, accessed 7 November 2023.

of reactors remains even if the Act expires). Price-Anderson was renewed in July 2023 through 2045 with no public hearings or debate, added as a rider to a must-pass defense spending bill.[1676]

Table 25 · Maximum Liability Coverage Levels for Nuclear Accidents

Country	Share of Global Nuclear Capacity (Operating, LTO, Under Construction)*	Operator Amount In Million US$	Domestic Supplement In Million US$, after operator amount exhausted	International Treaty Supplement In Million US$	Max, all tiers In Million US$
United States	21.55%	13,522	Guarantee of operator amount; additional with Action by Congress	116	13,638
China	17.25%	42	110m or above with State Council approval	NL	42
France	14.00%	767	1,316	329	2,412
Japan	7.34%	Unlimited	Action by Diet	116	116
Russia	6.78%	Unlimited	Available but amount not listed	NL	-
South Korea	6.34%	339	NL	NL	339
Canada	3.03%	753	Action by Parliament	116	869
India	2.85%	182	339	116	637
United Kingdom	2.03%	1,316	1,316	329	2,960
Spain	1.58%	1,316	1,316	329	2,960
Sweden	1.54%	Unlimited to selected neighbors, else reciprocity	1,316	329	1,644
Finland	0.98%	Unlimited inside; 1,315 max outside	1,316	329	1,644
Czech Republic	0.87%	368	min. 92	NL	368
Belgium	0.87%	1,316	1,316	329	2,960
Switzerland	0.66%	Unlimited	1,316	329	1,644
Slovakia	0.61%	329	NL	NL	329
Hungary	0.43%	113	226	NL	339
Germany	/	Unlimited	2,741	329	3,070

Sources: compiled by WNISR based on IAEA-PRIS, Liability data from NEA 2022[1677]

Notes: *As of 1 July 2023; **NL**: 'nothing listed'

Security and Proliferation

Radioactivity, and the connection between the nuclear fuel chain (and associated knowledge, skills, equipment, and technology) and potential weapons proliferation, both create unique risks associated with the nuclear energy pathway. When such costs are shifted to the public rather than recovered from the nuclear sector and reflected in prices, competitors to nuclear are disadvantaged.

1676 - Victor Gilinsky, "Senate extends nuclear liability-limiting law without public scrutiny. Here's why we should care", *Bulletin of the Atomic Scientists*, 22 August 2023, see https://thebulletin.org/2023/08/senate-extends-nuclear-liability-limiting-law-without-public-scrutiny-heres-why-we-should-care/, accessed 28 August 2023.

1677 - OECD/NEA, "Nuclear Operators' Third Party Liability Amounts and Financial Security Limits", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, Updated June 2022, see https://www.oecd-nea.org/upload/docs/application/pdf/2022-06/2020.10_operators_liability_amount_table_general_final_clean_v2_2022-06-30_13-34-34_716.pdf, accessed 22 July 2023.

In addition to the risk of diversion of weapons-related materials from the nuclear fuel chain, civilian nuclear activities can also contribute to latent proliferation. More facilities, associated training of more people, supply chains with potential dual use, and an ability to conceal military activities under the cloak of civilian power production, can all shorten the timeline for a country to become a nuclear weapons state. The IEA acknowledges that a very large number of small reactors built around the world would increase risks of proliferation.[1678]

These risks appear more significant for some reactor designs than for others. The most problematic are designs that entail or encourage the production, shipment, and use of direct weapons-usable materials like separated plutonium or high-enriched uranium.[1679] The use of high-assay low-enriched uranium (HALEU)[1680] is projected to grow to support a number of the newer designs and is an area of particular concern "because of the potentially greater attractiveness of this material for nuclear weapons compared with the low-enriched uranium used in light water reactors."[1681]

The Union of Concerned Scientists assessed the main emerging reactor technologies for their impact on plant safety and proliferation risks (see Table 26, below).[1682] It is notable that most of the designs were significantly worse in terms of safety, and generally worse in proliferation and terrorism risks. Reliance on HALEU is a common thread for many of these.

In terms of plant security, the design basis threat defines the core security risks for which reactors are expected to prepare. It is clear that these parameters do not adequately reflect current threat types (see Nuclear Power and War in WNISR2022). Nuclear plants have been targets in the Russian invasion of Ukraine, and damage to essential safety-relevant equipment affecting electricity supply or cooling chains, including intentional damage, has been and remains a continuing concern.

1678 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.91.

1679 - NTI, "Launch Event: The 2023 NTI Nuclear Security index", Nuclear Threat Initiative, 18 July 2023, see https://www.youtube.com/watch?v=ciX3TDC1qiI, accessed 19 July 2023.

1680 - HALEU is enriched to just below 20% in fissile Uranium-235 considered the limit of low enriched uranium. However, technically, the 20% enrichment level constitutes a significant step towards direct weapons usable high enrichment levels.

1681 - NASEM, "Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors", National Academies of Sciences, Engineering, and Medicine, 2023, p.182, see https://doi.org/10.17226/26500, accessed 21 July 2023.

1682 - Edwin Lyman, "'Advanced' Isn't Always Better— Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors", Union of Concerned Scientists, 18 March 2021, see https://doi.org/10.47923/2021.14000, accessed 21 July 2023.

Table 26 · Safety, Sustainability, and Proliferation Risks of Non-Light-Water Reactor Designs Compared to Light Water Reactors

Non-Light-Water Reactor Types	Safety	Sustainability		Nuclear Proliferation/ Terrorism
		Long-Lived Waste Generation	Resource Efficiency	
Sodium-Cooled Fast Reactors				
Conventional burner or breeder (Plutonium/TRU, with reprocessing)	– – –	++	+	– – –
Conventional: Natrium (HALEU, once-through)	– – –	– –	– –	– –
Breed-and-burn mode (HALEU, once-through)	– – –	– –	++	+
High-Temperature Gas–Cooled Reactors				
Prismatic-block (HALEU, once-through)	N	–	–	–
Pebble-bed: Xe-100 (HALEU, once-through)	N	–	–	– –
Molten Salt–Fueled Reactors				
Thermal: IMSR/TAP (LEU <5% U-235)	– – –	+	–	–
Thermal: Thorcon (HALEU/Thorium/U-233)	– – –	–	+	– –
Thermal: Molten Salt Breeder (HALEU/Thorium/U-233)	– – –	++	++	– – –
Molten Salt Fast Reactor (TRU/Thorium/U-233)	– – –	+++	++	– – –

Source: Union of Concerned Scientists, 2021[1683]

– – – Significantly Worse; – – Moderately Worse; – Slightly Worse

+++ Significantly Better; ++ Moderately Better; + Slightly Better; N Insufficient Information

TRU: Transuranic; **HALEU**: High-assay low enriched uranium; **LEU**: Low-enriched uranium; **IMSR/TAP**: Integral Molten Salt Reactor/Transatomic Power Corporation.

Even in 2019, drone attacks significantly damaged oil facilities in Saudi Arabia.[1684] That same year, the U.S. NRC declined to require key nuclear facilities, including nuclear power plants, to defend against unmanned aerial vehicles.[1685] And in September of 2019, a number of drones flew around restricted portions of the Palo Verde Nuclear Power Plant in the U.S. State of Arizona—an intrusion that plant owners were unable to stop.[1686] This information surfaced only due to a Freedom of Information Act request, so it is impossible to know how frequently,

1683 - Ibidem.

1684 - Ben Hubbard, Palko Karasz and Stanley Reed, "Two Major Saudi Oil Installations Hit by Drone Strike, and U.S. Blames Iran", *The New York Times*, 14 September 2019, see https://www.nytimes.com/2019/09/14/world/middleeast/saudi-arabia-refineries-drone-attack.html, accessed 21 July 2023.

1685 - UCS, "NRC Decision Leaves U.S. Nuclear Plants Vulnerable to Terrorist Drones", Union of Concerned Scientists, 4 November 2019, see https://www.ucsusa.org/about/news/nrc-decision-leaves-nuclear-plants-vulnerable-terrorist-drones, accessed 21 July 2023.

1686 - David Hamblin, "'Drone Swarm' Invaded Palo Verde Nuclear Power Plant Last September — Twice", *Forbes*, 30 July 2020, see https://www.forbes.com/sites/davidhambling/2020/07/30/drone-swarm-invaded-palo-verde-nuclear-power-plant/?sh=77c6449f43de, accessed 23 August 2023.

or how broadly, this type of surveillance is happening. Since then, both drone capabilities, and their distribution across state and non-governmental actors, have surged. Reports of drones at nuclear power plants continue to surface periodically, such as in Sweden in January 2022.[1687]

Efforts to quantify the cost of addressing specialized security risks of the nuclear fuel cycle are sparse, perhaps because spending is "spread across a hard to fathom number of budget lines." One recent estimate puts it at $4 billion per year to the U.S. industry, with an additional $1.1 billion annually spent on the international operations by the U.S. government.[1688] Similar costs incurred by other countries would be additional.

INDUSTRY CLAIMS REGARDING UNCOMPENSATED BENEFITS, FUTURE NEW MARKETS

Promoters of large-scale growth in nuclear power often claim that the observed economics of the resource don't tell the full story. Rather, they point to attributes of nuclear electricity for which it is not being properly compensated and highlight potential beneficial new opportunities for the high-capacity power generation to support markets they view as difficult to serve in other ways.

In its major 2018 study of the nuclear industry, for example, MIT referred to "under-remuneration of nuclear-generated electricity" driving premature closure of operating reactors.[1689] The authors pointed to inadequate compensation for nuclear's role as a provider of firm and high-capacity low-carbon electricity that was also dispatchable. Emerging market services that are supposed to help make the economics of nuclear work include hydrogen production, water desalination, supplying industries in need of high-temperature process heat, and behind-the-perimeter uses such as data centers and crypto mining.

These examples arise often enough to warrant some discussion. Production of hydrogen is addressed more completely because of large subsidies to nuclear hydrogen in the U.S. (possibly in addition to other new subsidies for generating the same electricity), and the potential impact of hydrogen scaling on the availability of low-carbon nuclear power for electricity consumers. Some cross-cutting constraints the industry faces are useful to frame in advance:

- First, aside from some limited cogeneration applications, the same reactor capacity can only supply low-carbon energy to one end-use at a time. If low-carbon electricity now sold to electricity consumers serves another use instead, benefit claims can only be attributed to one place and should no longer be claimed in the power sector. This aligns with the U.S. Federal Trade Commission guidance on renewable energy credits: if a generator of renewable energy sells the associated renewable energy credits, it can no longer claim the

1687 - Johan Ahlander, "Swedish Security Service investigates drones at three nuclear plants", *Reuters*, 17 January 2022, see https://www.reuters.com/world/europe/swedish-security-service-investigates-drones-three-nuclear-plants-2022-01-17/, accessed 23 August 2023.

1688 - Michal Barnard, "Nuclear Security Represents $4 Billion Annual Subsidy In US, Trillion All Costs For Fleet For Full Lifecycle", *Clean Technica*, 29 March 2021, see https://cleantechnica.com/2021/03/29/nuclear-security-represents-4-billion-annual-subsidy-in-us-trillion-for-fleet-for-full-lifecycle/, accessed 23 July 2023.

1689 - MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World—An Interdisciplinary MIT Study", Massachusetts Institute of Technology, 2018, pp.95–96, see https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf, accessed 21 July 2023.

generation is renewable.[1690] This fact also sets up a zero-sum game between low-carbon electrification and these other end-use markets. Carbon can be saved only once.

- Similarly, efforts to use "surplus" electricity from nuclear power plants to support new industries is effective only if those other industries can handle variable supply patterns. For capital-intensive industries that rely on nearly 24/7 production to be economic (such as hydrogen or desalination), a nuclear supplier would need to allocate a fixed percentage of production to that user. Thus, the alternative markets would compete with existing power customers, not supplement them.
- Third, efforts to ramp nuclear power plants to adjust to changing demands runs counter to the steady full-power plant operation needed to achieve needed cost targets. Further, technical constraints limit the speed and breadth of load following, and impose penalties in efficiency, maintenance cost, and plant lifetime.
- Fourth, despite MIT's claims, some of these attributes are already being compensated for in many markets. This includes low-carbon in markets where carbon is priced or nuclear is receiving out-of-market payments; and its reliability as a high-load-factor resource in regions that already provide capacity payments. Capacity mechanisms are common in most U.S. deregulated markets. While data are not available for the entire country, all operating merchant nuclear plants in the PJM (Pennsylvania-New Jersey-Maryland Interconnection) regional transmission organization earned some capacity payments in recent capacity auctions.[1691] Capacity payments have also been introduced in some European markets, including the U.K. and France; they are a common vehicle for adding further nuclear subsidies via electricity market rules.[1692]
- Finally, LCOEs for new nuclear remain higher than for alternative energy options. This poses a major impediment in all the proposed growth areas. New use cases for nuclear "cannot remedy uncompetitive electricity costs."[1693]

Hydrogen from Nuclear Reactors

Harder-to-decarbonize sectors such as long-distance air transport look to hydrogen produced from non-fossil resources as a solution. This includes production of hydrogen from nuclear reactors, which the nuclear industry views as a large growth opportunity. A survey by the Nuclear Energy Institute (NEI), the U.S. nuclear industry's trade association, found that nearly 60 percent of its members "are considering carbon-free hydrogen generation."[1694] France has

1690 - U.S. Federal Trade Commission, "Guides for the Use of Environmental Marketing Claims", Revised 2012, p.34, see https://www.ftc.gov/sites/default/files/attachments/press-releases/ftc-issues-revised-green-guides/greenguides.pdf, accessed 17 August 2023.

1691 - Nuclear Energy Institute, "Nuclear Plants in Cost of Service Regulation and Merchant Markets", Updated August 2022, see https://www.nei.org/resources/statistics/old/nuclear-plants-in-cos-regulation-merchant-markets; and Monitoring Analytics, LLC, "State of the Market Report for PJM: January through June", 10 August 2023, p.431, see https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2023/2023q2-som-pjm.pdf; both accessed 29 August 2023.

1692 - Muhammad Maladoh Bah, "State and federal nuclear support schemes in dynamic electricity market conditions: Insights from NYISO and PJM", *Energy Policy*, Vol. 182, November 2023, p.6, see https://doi.org/10.1016/j.enpol.2023.113764, accessed 28 August 2023; and IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p. 67.

1693 - Amory B. Lovins, "US nuclear power: Status, prospects, and climate implications", *The Electricity Journal*, Vol. 35, Issue 4, May 2022, p.6, see https://doi.org/10.1016/j.tej.2022.107122, accessed 21 July 2023.

1694 - Benton Arnett, "Everyone Wants Clean Hydrogen – Nuclear Can Deliver", NEI Blog, Nuclear Energy Institute, 8 June 2023, see https://www.nei.org/news/2023/everyone-wants-clean-hydrogen-nuclear-can-deliver, accessed 17 August 2023.

pushed for nuclear-derived hydrogen to be counted as clean energy.[1695] In the United States, proposed rules by the U.S. Environmental Protection Agency would allow co-firing of low carbon hydrogen with natural gas to achieve acceptable CO_2 levels under the new regulatory environment.[1696] While large subsidies in the U.S., E.U., and possibly in other countries as well may make it possible for existing reactors to enter this market—especially if they can double-dip both generation and hydrogen-production subsidies—the environmental benefits will depend on whether the hydrogen is using clean energy that would otherwise be curtailed rather than diverting clean electricity to make hydrogen that could otherwise displace more power-plant fossil fuel, or, even worse, driving up total power demand so highly-polluting fossil generators are kept online longer.

Several factors suggest that subsidized nuclear hydrogen production will have limited environmental benefits. First, hydrogen infrastructure is expensive and needs to run nearly 24/7 to provide a marketable product. As a result, using only surplus power from certain times of day would not suffice to support this business line, which instead would pull slices of nuclear capacity (up to entire reactors) away from low-carbon electricity and towards dedicated hydrogen production. Pilot projects in a few locations in the U.S. aim to demonstrate flexible plant operation to produce the hydrogen during times of high wind or solar supply to the grid.[1697] But utilization rates of the electrolyzer also matter a lot: "For example, it has been shown that with other factors held constant, the LCOH [Levelized Cost of Hydrogen] triples when moving from a 90 percent capacity load factor electric source (e.g. nuclear) to 20 percent load factor (e.g., solar)."[1698] NAS uses this example to illustrate why a renewable pathway to hydrogen would be more expensive than a nuclear pathway; however, it also underscores that the nuclear pathway would need to divert power consistently from decarbonizing electricity markets to produce hydrogen efficiently.

The need for continuous operation to be economic is driven by the hydrogen customers as well; "[n]early all major industrial processes that would utilize clean hydrogen (including fertilizers, building materials, fuels and plastics) need a continuous hydrogen stream to run effectively. Generally operating at high temperature, these processes cannot simply shut down whenever renewables are unavailable."[1699] However, hydrogen can be stored at reasonable cost, and assumed needs for high load factors depend on assumed technologies. For example, a major projected use of hydrogen is iron production, but emerging lower-temperature electrochemical

1695 - Michel Rose, Belén Carreño and Kate Abnett "France in new row with Germany and Spain over nuclear-derived hydrogen", *Reuters*, 9 February 2023, see https://www.reuters.com/business/sustainable-business/france-new-row-with-germany-spain-over-nuclear-derived-hydrogen-2023-02-08/, accessed 17 August 2023.

1696 - Kevin Clark, "EPA proposes carbon emission limits on coal and gas-fired plants", *Power Engineering*, 11 May 2023, see https://www.power-eng.com/emissions/epa-proposes-strict-emission-limits-on-coal-and-gas-fired-plants/#gref, accessed 23 August 2023.

1697 - NASEM, "Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors", 2023, op. cit., p.91.

1698 - NASEM, "Chapter 5—Beyond Electricity: Nuclear Power's Potential to Play a Broader Role in the Future Energy System" in National Academies of Sciences, Engineering, and Medicine, "Laying the Foundation for New and Advanced Nuclear Reactors in the United States", *The National Academies Press*, 2023, op. cit., p.82.

1699 - AGRU America, Air Company, et al., "Re: How annual matching for the Inflation Reduction Act's (IRA) 45V clean hydrogen tax credit can accelerate", Letter to Janet Yellen, U.S. Treasury; Jennifer Granhold, U.S. Department of Energy; and John Podesta, Senior Advisor to the President for Clean Energy Innovation and Implementation, White House, 12 April 2023, see https://subscriber.politicopro.com/f/?id=00000187-76b0-d820-a7e7-7eb4954e0000, accessed 16 August 2023.

approaches look promising and need neither steady operation nor high-grade ore.[1700] Similar methods are emerging for magnesium, titanium, and aluminum, all of which could reduce the long-term need for industrial hydrogen.

Lazard's analysis of the Levelized Cost of Hydrogen (LCOH) found that production from nuclear would be less expensive than from renewable energy, a difference "almost entirely down to the higher capacity factors achievable with nuclear power",[1701] and highlighting the limitations in trying to use power from reactors when it is intermittently in surplus. The analysis assumed a load factor of 95 percent for nuclear versus 55 percent for renewables,[1702] clearly indicating diversion of a consistent share of reactor production from power markets to hydrogen production. IEA also proposed diversion of entire nuclear power plants to hydrogen, arguing that providing a steady flow of hydrogen to industrial customers would reduce the needed scale of hydrogen pipelines and storage.[1703] In France, advocates for nuclear-powered electrolysis have argued that "nuclear's ability to run electrolysers uninterrupted at maximum capacity can help decarbonized H_2 rapidly achieve cost parity with existing supplies."[1704] However, low hydrogen production costs are already occurring by other means: in late 2020, about a decade before most projections, Chinese chemical firm Baofeng made US$2.7/kg hydrogen from its 1-GW PV power plant.[1705]

Further, Lazard assumed that nuclear power would be derived from an *existing* nuclear power plant, noting that the LCOE of long-term operation (basically extending the service life of existing reactors) is well known to be the most competitive portion of the nuclear industry.[1706] IEA concurred, noting that based on current economics "new nuclear power plants as a power source for electrolysers appear unlikely to be competitive with renewables or fossil fuels with CCUS to produce hydrogen in many parts of the world."[1707] They suggest using curtailed nuclear to produce hydrogen would be more beneficial, while acknowledging that the capability to do that in reality depends on many other factors (how much surplus, whether it can be sold at a higher price through the grid elsewhere, the size and economics of the electrolyzer).[1708]

Of note, U.S. policy now appears to offer large subsidies to hydrogen production that can be taken on top of subsidies to nuclear plants. The E.U. plans to launch a hydrogen fund to provide a flat subsidy per kg of clean hydrogen produced. The dollar commitment will be fixed

1700 - Electra, "Electra Partners with Nucor to Usher in a New Era of Green Steelmaking", Press Release, as published on *Business Wire*, 8 December 2022, see https://www.businesswire.com/news/home/20221208005334/en/Electra-Partners-with-Nucor-to-Usher-in-a-New-Era-of-Green-Steelmaking, accessed 14 November 2023.

1701 - Rachel Parkes, "'Nuclear hydrogen could be made in the US for less than $0.50/kg — cheaper than green H2': Lazard", *HydrogenInsight*, 14 April 2023, see https://www.hydrogeninsight.com/production/nuclear-hydrogen-could-be-made-in-the-us-for-less-than-0-50-kg-cheaper-than-green-h2-lazard/2-1-1437441, accessed 22 July 2023.

1702 - Lazard, "LCOE+", 12 April 2023, op. cit., p.54.

1703 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.70.

1704 - Anderw Lee, "Macron hails pink hydrogen from nuclear as 'primary asset' for France", *Recharge News*, 21 October 2021, see https://www.rechargenews.com/energy-transition/macron-hails-pink-hydrogen-from-nuclear-as-primary-asset-for-france/2-1-1086259, accessed 17 August 2023.

1705 - Amory B. Lovins, "US nuclear power: Status, prospects, and climate implications", *The Electricity Journal*, 1 May 2022, op.cit.

1706 - Rachel Parkes, "'Nuclear hydrogen could be made in the US for less than $0.50/kg — cheaper than green H2': Lazard", *HydrogenInsight*, 14 April 2023, see https://www.hydrogeninsight.com/production/nuclear-hydrogen-could-be-made-in-the-us-for-less-than-0-50-kg-cheaper-than-green-h2-lazard/2-1-1437441, accessed 22 July 2023.

1707 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit., p.73.

1708 - Ibidem, p.75.

at €800 million (US$858 million) in the first round and awarded in an auction format.[1709] However, at least at this stage, hydrogen produced from nuclear does not appear eligible.[1710]

It is possible that the subsidies, rather than value in the market, will pull nuclear power plants out of the power market and into the hydrogen production business. As noted in United States Focus, the Hydrogen Production Tax Credit (PTC), under §45V of the Inflation Reduction Act, is both large and lucrative. The US$3/kg value of this new subsidy could translate into an electricity subsidy of US$56–72/MWh—nearly four to five times the maximum value of the Nuclear PTC and substantially greater than the average market price of electricity. Although the rules seem to require that nuclear generation and hydrogen production be owned by different legal entities, the stacked subsidies would be very large if allowed.[1711] Firms may therefore decide to divert power from the grid to hydrogen production and arrange corporate structures to comply, though the statute defines power from a related party as "sold" if used to produce clean hydrogen, so restructuring may not even be needed.[1712] Indeed, the value of the hydrogen PTC alone "motivates hydrogen producers to operate their electrolyzers at very high utilization rates year-round, and to continue consuming electricity even when high-price resources like coal and gas are on the margin."[1713] Because the tax credits are uncapped, revenue losses could exceed US$100 billion depending on Internal Revenue Service guidelines on who can claim them.[1714]

Political battles are now ongoing in two main areas of hydrogen tax credit eligibility. The first is on "additionality"—that only *new* producers of low-carbon electricity could claim 45V tax credits, which the Nuclear Energy Institute (NEI), the U.S. nuclear industry's lobby organization, opposes.[1715] Allowing existing producers to claim the credit increases the chance that the limited existing supply of low-carbon power will be diverted to hydrogen production rather than growing the market for low-carbon power producers and directly displacing power plants that burn roughly three units of fossil fuel per unit of electricity. Ironically, heavy subsidies to nuclear power for hydrogen production can divert low carbon electricity to make hydrogen that is then used to feed co-firing with natural gas to again produce "clean" electricity.

1709 - Kate Abnett, "EU plans subsidies for hydrogen made using renewable energy -draft document", *Reuters*, 16 March 2023, see https://www.reuters.com/business/energy/eu-plans-subsidies-hydrogen-made-using-renewable-energy-draft-document-2023-03-16/, accessed 17 August 2023.

1710 - Leigh Collins, "ANALYSIS | No, the EU's new Delegated Act does not allow green hydrogen to be made from nuclear power", *Hydrogen Insight*, Updated 14 February 2023, see https://www.hydrogeninsight.com/policy/analysis-no-the-eus-new-delegated-act-does-not-allow-green-hydrogen-to-be-made-from-nuclear-power/2-1-1403726 accessed 17 August 2023.

1711 - NASEM, "Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors", 2023, op. cit., p.92.

1712 - See 26 USC 45(e)(13)(A), see https://www.law.cornell.edu/uscode/text/26/45#e, accessed 7 November 2023.

1713 - Wilson Ricks, Qingyu Xu and Jesse D Jenkins, "Letter—Minimizing emissions from grid-based hydrogen production in the United States", *Environmental Research Letters*, Vol. 18, No. 1, 6 January 2023, p. 5, see https://iopscience.iop.org/article/10.1088/1748-9326/acacb5/meta, accessed 17 July 2023.

1714 - Pete Budden and Rachel Fakhry, "IRA Clean Hydrogen Tax Credit: Debunking Five Myths", Natural Resources Defense Council, 24 April 2023, see https://www.nrdc.org/bio/pete-budden/ira-clean-hydrogen-tax-credit-debunking-five-myths, accessed 16 August 2023.

1715 - Nuclear Energy Institute, Constellation et al., "Re: Notice 2022-49 Request for Comments on Certain Energy Generation Incentives – Hydrogen (IRC Section 45V)", Letter addressed to Lily Batchelder, Department of Treasury and William Paul, Internal Revenue Service, 24 May 2023, see https://www.nei.org/CorporateSite/media/filefolder/resources/letters-filings-comments/Joint-Response-to-NRDC-CATF-comment.pdf accessed 17 August 2023.

A second area of contention involves what emissions averaging is allowed to meet the thresholds behind the 45V credit. Since the credit rises as emissions per unit hydrogen decline, how the emissions factor is calculated will drive what is counted as clean hydrogen, and with it, the allocation of billions of dollars of subsidies to the nuclear sector. A central issue relates to matching the clean energy consumed to supply electrolyzer demand on an hourly basis, versus matching the two as infrequently as annually. Behind-the-meter hydrogen production from renewable plants or a nuclear reactor allow fairly good attribution of direct emissions but may still drive up attributional emissions as these cleaner resources are diverted to hydrogen production and power markets pull in more high-carbon generation resources to backfill supply for electricity consumers. The larger the scale of hydrogen production, the bigger this issue becomes.

If grid energy is used for the electrolyzer instead, attribution even of direct emissions becomes more challenging for a few reasons. First, if clean energy is purchased concurrent with electrolyzer demand, but from far away, there may be delivery constraints that mean in reality the clean energy never reached the service area as claimed and carbon emissions rise as a result.[1716] Similarly, if the matching of clean generation with hydrogen production is too loose, a hydrogen facility could purchase surplus wind power at night, for example, and claim clean production when in reality demand was during constrained hours or seasons for which electrolyzer demand actually brought in high carbon generators to supply the grid. Grid modeling does indicate that monthly or annual matching is associated with much higher carbon intensities on the produced hydrogen than is hourly matching.

Desalination and Industrial Heat

Desalination and production of heat for industrial processes are mentioned as important benefits of a growing nuclear power sector. A selling point is that nuclear, and particularly some SMR technologies, are "targeting some of the most difficult tasks of energy transitions."[1717] There are some existing examples of nuclear reactors being used for district heat production or desalination. A handful of plants also produce heat used in industrial processes, though they serve relatively low-temperature applications (<250 degrees C.)[1718] Whether to use a nuclear power plant for more than power generation, and which kind, depends on the temperature required for the application.[1719]

Integrated power and industrial production for a nuclear power plant is more complicated if heat as well as power is needed, due to needs for integration and co-location.[1720] And, as with hydrogen production, cost and technical considerations are likely to impede desalination and industrial heat from scaling in a meaningful time frame to address climate

1716 - Wilson Ricks, Qingyu Xu and Jesse D Jenkins, "Letter—Minimizing emissions from grid-based hydrogen production in the United States", op. cit.

1717 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, International Energy Agency, September 2022, op. cit., p.87.

1718 - IAEA, "Opportunities for Cogeneration with Nuclear Energy", IAEA Nuclear Energy Series, No. NP-T-4.1, 2017, pp. 15–17, see https://www-pub.iaea.org/MTCD/Publications/PDF/P1749_web.pdf, accessed 23 August 2023.

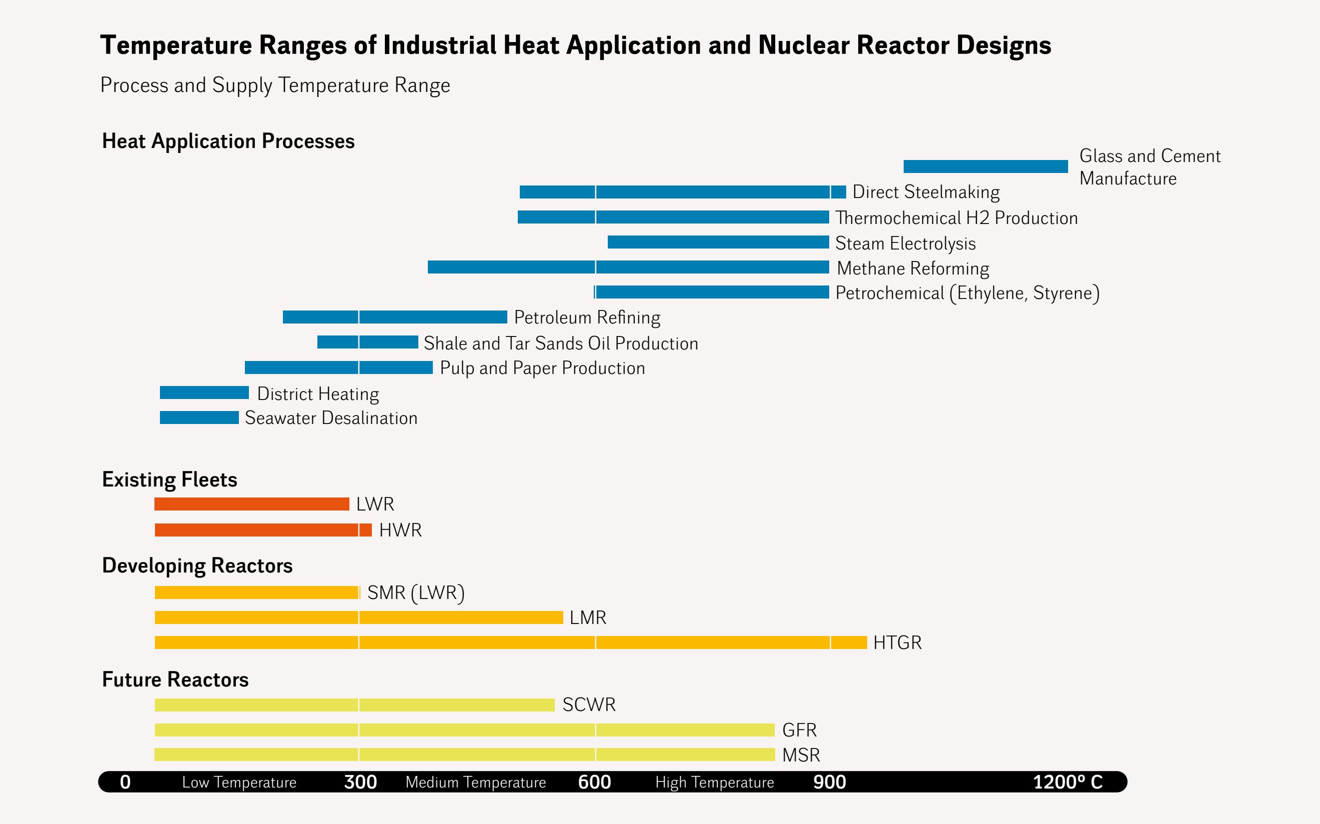
1719 - NASEM, "Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors", 2023, op. cit., p.86.

1720 - Ibidem, p.90.

change. Figure 61 below illustrates heat production temperatures by reactor type versus the temperatures needed by key industries associated with the "most difficult tasks" of the energy transition. The relatively low process heat temperatures at existing reactors mean that they can only serve a limited subset of applications. And even here, delivery infrastructure is expensive, and the consuming sector needs to be co-located to the plant, further limiting available markets.

The most important industrial markets with higher temperature needs are likely to require SMRs and reactor types that have significant commercial and cost uncertainties. Further, these will also need to be co-located with the industrial facility, and able to supply it 24/7 since the industrial processes require high load factors to be economic. This suggests dedicated reactors rather than servicing these markets as a "side business" to electric power customers. Further, if the thermal process requires continuous operation, some redundancy of nuclear capacity will need to be provided to guard against outages. This is among the challenges of using nuclear power for remote military or civilian installations.

Figure 61 · Temperature Ranges of Industrial Heat Application and Nuclear Reactor Designs



Source: IAEA, 2017[1721]

Type of Reactors:

GFR: Gas-cooled Fast Reactor; **HTGR**: Hight Temperature Gas Reactor; **HWR**: Heavy Water Reactor; **LMR**: Liquid Metal Reactor; **LWR**: Light Water Reactor; **MSR**: Molten Salt Reactor; **PWR**: Pressurized Water Reactor; **SCWR**: Supercritical Water Reactor; **SMR**: Small Modular Reactor.

1721 - IAEA, "Opportunities for Cogeneration with Nuclear Energy", IAEA Nuclear Energy Series, No. NP-T-4.1, 2017, op cit., p. 12.

Desalination approaches relying predominantly on electricity can more easily use existing reactors and facilities located farther away. However, these desalination plants also need to run essentially non-stop to be economic: a review of alternative technologies found that "the plant capacity utilization (the percent of time during the year that the plant is operating at nominal capacity) had the largest impact on the LCOW [Levelized Cost of Water]. This result suggests reducing plant downtime from fouling, cleaning, and replacement to ensure continuous water production at designed capacity is critical to reduce the overall LCOW over the plant service life."[1722] Running desalination equipment under a minimum production rate scenario (similar to what would happen if surplus nuclear were diverted rather than a slice of firm capacity) "has been shown to be highly energy inefficient compared to operation at its design capacity." [1723]

Further, because desalination is energy-intensive, the high cost of SMRs makes it a poor choice. Modeling of desalination using either SMRs or natural gas with carbon capture and storage found that "the cost of carbon emissions would have to rise to [US]$200/t$CO_2$ for the SMR solution to clearly dominate the natural gas option," and that heavily subsidized water prices (which often dominate even in arid regions in many parts of the world) weakened the economic case for any form of desalination.[1724] In some limited circumstances, use of existing reactors in arid regions for desalination could make sense, such as to avoid severe groundwater overdrafts or to delay or avoid the need for expensive water diversion projects.[1725] The example given by the National Academy of Sciences was the Diablo Canyon plant in California. However, that plant has received subsidies to remain in operation to support low carbon electric power markets, not ancillary services, highlighting again the conflicts that arise when ancillary uses cannot rely on variable power generators.[1726] Further, demand-side options to reduce water needs may be less expensive than new water supply projects, recycling, or desalination.[1727] Such options do, however, also rely on accurate pricing of both water and water treatment services—clearly an attribute far from reality for nuclear power.

Nuclear as Dispatchable Power Source

In today's power markets, large fluctuations over days or seasons in power availability and price are becoming more common. Concurrent with this is an increasing ability to adjust demand. With these conditions, the ability to also adjust power production so it better matches market conditions becomes increasingly valuable. With the notable (though limited) exception of France, which overbuilt its nuclear fleet (then promoted costly resistive heating of inefficient buildings to soak up some of the surplus), there is little history of load-following at nuclear

1722 - Hunter Quon, Joshua Sperling et al., "Pipe Parity Analysis of Seawater Desalination in the United States: Exploring Costs, Energy, and Reliability via Case Studies and Scenarios of Emerging Technology", *ACS ES&T Engineering*, Vol. 2, Issue 3, 11 March 2022, pp.434–445, see https://doi.org/10.1021/acsestengg.1c00270, accessed 22 July 2023.

1723 - Ibidem.

1724 - NASEM, "Laying the Foundation for New and Advanced Nuclear Reactors in the United States", National Academies of Sciences, Engineering, and Medicine, *The National Academies Press*, 2023, p.86, op. cit.

1725 - Ibidem.

1726 - California Energy Commission, "CEC Determines Diablo Canyon Power Plant Needed to Support Grid Reliability", 28 February 2023, see https://www.energy.ca.gov/news/2023-02/cec-determines-diablo-canyon-power-plant-needed-support-grid-reliability, accessed 29 August 2023.

1727 - Doug Koplow and Alexi Lownie, "Cost Accounting and Budgeting for Improved Wastewater Treatment", February 1998, prepared for the U.S. Environmental Protection Agency, see https://www.epa.gov/system/files/documents/2023-05/costaccountingandbudgeting1998.pdf, accessed 29 August 2023.

plants. Instead, operators have focused on maximizing load factors to spread large fixed costs widely. In its modeling of energy scenarios to achieve net zero by 2050, the International Energy Agency put the nuclear share of hour-to-hour flexibility in advanced economies at only two percent today—or just one percent in emerging markets and developing economies. Projected shifts by 2050 were relatively modest, reaching 5 percent for advanced economies and 3 percent for the others.[1728]

And yet, claims that the resource is dispatchable are regularly mentioned as an attribute. The OECD's Nuclear Energy Agency, for example, noted that "…nuclear power will become increasingly attractive owing to its attributes as a low-carbon, dispatchable and flexible technology."[1729] However, flexible dispatch of nuclear runs into both technical and economic constraints.

On the economic side, ramping power down conflicts with economies of scale. Even under favorable assumptions on overnight capital costs, and ignoring technical constraints on ramping, WIP/DIW Berlin found that nuclear plants would need to "operate inflexibly and at utilization rates close to 90%" in order to recover their investment costs due to rising fixed costs per unit output.[1730] They concluded that other sources of flexibility may be less expensive, such as power imports from interconnected regions; and that [1731] "[d]espite its assumed flexibility, nuclear power rather substitutes than complements fluctuating supply from wind and solar generation.[1732] Within the U.S. PJM power pool, which serves more than 60 million people, a small number of nuclear units have been offered with a dispatchable range since 2015. In this scenario, the system operator can instruct these resources to adjust their operating levels in response to system conditions. However, the system operator noted that this process does not always work, since "the dispatchable nuclear units do not always respond to dispatch instructions" to adjust their production.[1733]

Modeling of the benefits from nuclear curtailment—due to reduced losses to other generators (mostly renewable), reduced hours with negative prices, and the ability of the reactor to provide frequency modulation and reserve services with its curtailed capacity—also indicated that economic rather than technical factors constrained how much ramping was done. The economics of these shifts were positive or neutral for the nuclear operator, though even in the scenario that assumed the highest flexibility, and with some ramping during nearly one-quarter of its operating hours, total nuclear generation remained more than 94 percent of its baseline production levels.[1734] The implication is that curtailed nuclear would not be sufficient

1728 - IEA, "Nuclear Power and Secure Energy Transitions", Revised Version, September 2022, op. cit. p.48.

1729 - NEA, "Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders", 2020, p. 125.

1730 - Leonard Göke, Alexander Wimmers and Christian von Hirschhausen, "Economics of Nuclear Power in Decarbonized Energy Systems", Workgroup for Infrastructure Policy (WIP), Technical University of Berlin, and Energy, Transportation, Environment Department, German Institute for Economic Research/Deutsches Institut für Wirtschaftsforschung (DIW), Preprint, 14 March 2023.

1731 - DIW and WIP, "Economics of Nuclear Power in Decarbonized Energy Systems", Preprint, 14 March 2023, op. cit., p.6.

1732 - Ibidem, p.9.

1733 - Monitoring Analytics, LLC, "State of the Market Report for PJM: January through June", 10 August 2023 p. 200, see https://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2023/2023q2-som-pjm.pdf, accessed 29 August 2023.

1734 - J. D. Jenkins, Z. Zhou et al. "The Benefits of Nuclear Flexibility in Power System Operations with Renewable Energy", Massachusetts Institute of Technology and Argonne National Laboratory, published in *Applied Energy*, Vol 222, 15 July 2018, p. 879, see https://doi.org/10.1016/j.apenergy.2018.03.002, accessed 23 July 2023.

to service ancillary businesses, nor could the same kWh be both used for grid stabilization and sold to alternative consumers.

Significantly higher load following and ramping schemes, in frequency as well as amplitude, might have significant impact on nuclear-plant materials. EDF's executive director for the nuclear fleet told the French National Assembly in January 2023 that, while no accelerated wearing has been identified on the primary circuit, "the technical debate is more intensive on the secondary circuit" as "a certain number of parts suffer more than others". Convinced that modularity will increase with increasing renewables penetration and climate change effects, questions arise whether "potential accelerated aging" would be triggered if power modulation was increased from current practice. The parliamentary committee report concluded: "Overall, the modulation of nuclear production increases maintenance requirements."[1735]

Dedicated Reactors

While the use of surplus nuclear energy at scale for other uses seems unlikely in the near term due to the rigorous demands on the consumption side, a handful of experiments for dedicated SMRs tied to remote or specialized uses have been taken up. An agreement between Dow Chemical and X-energy for a 4-unit, 320 MWe SMR installation at the company's Seadrift facility in Calhoun County, Texas, is one example. The facility would be used for joint heat and power.[1736] The cost of these demonstration projects will be quite high and rely heavily on government subsidies. Whether dedicated reactors ever become competitive will depend on whether costs come down sharply or not; the industry has not been successful in doing so in the past. Microsoft recently posted a job listing for a management-level hire to vet the use of SMRs to power its data centers. This type of application is similar to the Dow/X-energy approach, in that a dedicated high-load-factor low-carbon resource will potentially be paired with a dense demand center to address decarbonization concerns and avoid reliance on grids. Microsoft is also using hourly matching to integrate existing nuclear generation to power a data center in Virginia, an effort to supplement wind and solar supply and thereby achieve zero carbon power around the clock.[1737] A similar deal has been signed between Constellation and Commonwealth Edison for its 54 offices and metered facilities.[1738] Expansion of this approach will depend on new nuclear being cost-competitive, which it isn't yet. In the near-term, scaling of dedicated low-carbon supply from existing nuclear reactors to support a larger demand base seems likely to put these buyers in conflict with residential and commercial grid users during periods when wind or solar generation is low.

1735 - Raphaël Schellenberger and Antoine Armand, "Rapport d'enquête n°1028— Rapport fait au nom de la Commission d'enquête visant à établir les raisons de la perte de la souveraineté et d'indépendance énergétique de la France—Tome I—Rapport", Assemblée Nationale, filed 30 March 2023.

1736 - Sonia Patel, "X-Energy, Dow Unveil Texas Site for ARDP Nuclear Demonstration", *POWER Magazine*, 11 May 2023, see https://www.powermag.com/x-energy-dow-unveil-texas-site-for-ardp-nuclear-demonstration/, accessed 27 September 2023.

1737 - *Power Engineering*, "Microsoft job posting signals commitment to small nuclear reactors for powering data centers", 25 September 2023, see https://www.power-eng.com/nuclear/microsoft-job-posting-signals-commitment-to-small-nuclear-reactors-for-powering-data-centers/#gref, accessed 27 September 2023.

1738 - *Business Wire*, "Constellation Inks Deal With Major U.S. Utility for 100 Percent Hourly Carbon-Free Energy Matching", 14 September 2023, see https://finance.yahoo.com/news/constellation-inks-deal-major-u-130000528.html, accessed 27 September 2023.

ECONOMIC PERFORMANCE OF KEY PLAYERS

Implicit in increasing government interventions to bolster the nuclear sector is that key firms were not doing particularly well without this government support. This section provides an overview of six major international players and potential nuclear builders: Rosatom (Russia), CGN/CNNC (China), EDF/Framatome (France), Westinghouse (U.S./Canada), KEPCO (South Korea), and Toshiba (Japan). Also included is Constellation in the U.S., a main beneficiary of state-level subsidies.

Électricité de France (EDF)

As noted above, Électricité de France (EDF) is the largest reactor operator in the world, but due to financial challenges—predominantly from problems with prolonged reactor outages and needed repairs at its fleet of operating reactors, as well as cost overruns at its construction projects in France and the U.K.—the company was fully renationalized in October 2022. The immediate taxpayer cost of this about-face from partial shareholder ownership was nearly €10 billion (US$$_{2022}$10.5 billion).[1739] EDF debt levels were very high, and state ownership was viewed as a credit positive by ratings agencies. S&P noted that "[w]e believe state support increasingly drives EDF's creditworthiness in the new energy landscape," and Fitch similarly wrote that "[n]ationalization is credit positive." [1740]

After large losses in 2022, the company swung to profit during 2023 due to higher power prices and a reduction in nuclear power plant outages.[1741] Also benefitting EDF were two government decisions: a reduction in required discounted power sales under the ARENH agreement from 2022 levels, increasing market-priced sales by 20 TWh; and an agreement for the government to subsidize power consumers if prices rose above €325/MWh (US$342/MWh), reducing political pressure to control energy prices by restricting utility price increases.[1742]

However, long-standing tensions over pricing between the French government and EDF managers remain. This is complicated by the expiration of the ARENH agreement in 2025, and determining what should replace it, while still satisfying E.U. requirements for some semblance of avoiding overt state support. EDF debt is already high at €65 billion (US$68.7 billion), so management does not want to fund more capital spending predominantly with debt, but rather to increase revenues. Reactors play a central role in these tensions, as the government wants

1739 - *WNN*, "State takeover of EDF resumes after appeal dismissed", *World Nuclear News*, 3 May 2023, see https://www.world-nuclear-news.org/Articles/State-takeover-of-EDF-resumes, accessed 21 July 2023.

1740 - S&P Global Ratings, "Research Updated: EDF Affirmed At 'BBB/A-2' As Stronger State Support Mitigates Operational Issues And Debt Growth; Outlook Stable", 14 December 2022, see https://www.edf.fr/sites/groupe/files/2022-12/sp-edf-ratings-direct-2022-12-14.PDF; Fitch Ratings, "Rating Action Commentary Fitch Revises EDF's Outlook to Stable; Affirms at 'BBB+'", 6 September 2022, see https://www.fitchratings.com/research/corporate-finance/fitch-revises-edf-outlook-to-stable-affirms-at-bbb-06-09-2022; both accessed 7 November 2023.

1741 - Forrest Crellin and Benjamin Mallet, "EDF swings to profit thanks to price increases", *Reuters*, 27 July 2023, see https://www.reuters.com/business/energy/edf-swings-back-profit-h1-thanks-price-increases-2023-07-27/, accessed 27 September 2023.

1742 - Tassilo Hummel and Dominique Vidalon, "France cuts volume of nuclear power EDF must sell cheaply in 2023", *Reuters*, 27 October 2020, see https://www.reuters.com/business/energy/france-reduces-volume-nuclear-power-utility-edf-must-sell-cheap-2023-2022-10-27/, accessed 27 September 2023.

EDF to build at least six new reactors in France at an estimated cost of more than €50 billion (US$$_{2023}$54.7 billion), as well as being behind and over budget on nuclear projects outside of France (see also United Kingdom Focus).[1743] The company's Flamanville-3 EPR reactor is now estimated to open in the first quarter of 2024, twelve years late and at a price tag of at least €$_{2015}$13.2 billion (€$_{2023}$15 billion or US$$_{2023}$16 billion).[1744] As noted above, in 2020, the Court of Accounts calculated financing and other costs would reach €$_{2015}$6.7 billion (€$_{2023}$8 billion or US$$_{2023}$8.6 billion) for a startup then scheduled for 1 July 2023.[1745] The total would thus reach €$_{2023}$23 billion (US$$_{2023}$24.6 billion). However, financing and other costs' estimates have not been updated to the revised startup schedule.

Rosatom

State-owned Rosatom controls most aspects of civilian nuclear power and military applications in Russia. The Rusatom Overseas subsidiary, "involved in Rostom's corporate development, with stated goals of building up Rosatom's overseas nuclear power plant order portfolio and maintaining Russia's leading position in the global nuclear market" is already under U.S. sanctions.[1746]

However, despite the invasion of Ukraine, Rosatom's claimed exports rose 15 percent in 2022, and foreign orders were reportedly stable at US$200 billion.[1747] The sanctions may be of limited efficacy so far, with one commentor concluding that

> The new sanctions levelled against individuals and legal entities connected with Rosatom have yet to have a serious influence on the international and domestic business of the corporation, and on its ability to promote the interests of the Russian leadership. In many ways these sanctions simply duplicate sanctions that were previously levelled in other jurisdictions, where Rosatom structures included on the sanctions list do not conduct activity.[1748]

Russian nuclear fuels, whether natural and enriched uranium or manufactured fuel assemblies, remain unsanctioned. Although development of substitutes, such as enriched uranium through Urenco, will increase supply security over time, the U.S. and Europe purchased US$1.7 billion worth of Russian fuels and related products (of US$2.2 billion total) during 2022. French imports of enriched uranium from Russia nearly tripled between 2021 and 2022.[1749]

1743 - Sarah White and Leila Abboud, "EDF chief and French government clash over strategy", *Financial Times*, 24 September 2023, see https://www.ft.com/content/eaee5a3d-ba76-40ba-8300-082f586574e8, accessed 27 September 2023.

1744 - EDF, "The 2022 Universal registration document including the annual financial report", 4 October 2023, see https://www.edf.fr/en/the-edf-group/dedicated-sections/investors/regulated-information, accessed 3 November 2023.

1745 - Cour des Comptes, "La filière EPR", 9 July 2020 (in French), see https://www.ccomptes.fr/fr/publications/la-filiere-epr, accessed 8 November 2023.

1746 - U.S. Department of State, "Further Curbing Russia's Efforts to Evade Sanctions and Perpetuate its War against Ukraine: Fact Sheet", United States Government, 12 April 2023, see https://www.state.gov/further-curbing-russias-efforts-to-evade-sanctions-and-perpetuate-its-war-against-ukraine-2/, accessed 27 September 2023.

1747 - *Reuters*, "Russia's Rosatom sees 2022 exports growth at 15% - report", 25 December 2022, see https://www.reuters.com/business/energy/russias-rosatom-sees-2022-exports-growth-15-report-2022-12-26/ accessed 20 September 2023.

1748 - Charles Digges, "Bellona's nuclear digest for July 2023", Bellona, 24 August 2023, see https://bellona.org/news/nuclear-issues/2023-08-bellonas-nuclear-digest-for-july-2023#_Toc143694577, accessed 20 September 2023.

1749 - Martha Mendoza and Dash Litvinova, "Putin profits off US and European reliance on Russian nuclear fuel", *The Associated Press*, 10 August 2023, see https://apnews.com/article/russia-ukraine-war-us-europe-nuclear-exports-4129cbea2aaa69b1da5d09a41804f745, accessed 27 September 2023.

China General Nuclear Power Group (CGN) and China National Nuclear Corporation

CGN is rated well by Fitch due to linkage to the Chinese government, which "appoints its key management and controls its major business and financial decisions." The company receives frequent funding from the government, including both direct support (CNY2.5 billion [~US$$_{2021}$388 million] in 2021 and CNY2.9 billion [~US$$_{2020}$420 million] in 2020) and equity infusions.[1750]

Nonetheless, CGN, the only major Chinese nuclear company listed on the Hong Kong stock exchange, lost three-quarters of its stock value since December 2021.[1751]

CGN and the other major Chinese nuclear player, CNNC, have both been blacklisted by the U.S. government, complicating their international expansion in the nuclear sector.

Westinghouse

Westinghouse Electric Company, a subsidiary of Toshiba at the time, declared bankruptcy in March 2017 due to losses on reactor projects in the U.S. The Vogtle reactors in Georgia and the VC Summer plant in South Carolina both experienced large cost overruns and delays. Westinghouse agreed to pay US$3.7 billion to Vogtle and US$2.17 billion to Summer to walk away from the projects.[1752] Westinghouse was purchased in 2018 from Toshiba by Brookfield Business Partners (BBP) and Brookfield Asset Management (BAM), both part of the Canadian holding company Brookfield Corporation. The estimated value at that time was US$4.6 billion.[1753] In October 2022, Brookfield Renewable Partners (51 percent) and nuclear fuel supplier Cameco (49 percent) purchased Westinghouse from BBP and BAM for US$7.9 billion. The service portion of the business looked attractive, since Westinghouse reactor technology is used in "about half" of the world's nuclear reactors.[1754] Westinghouse also has major investments in reactor development, through the AP100 PWR and the AP300, smaller versions of the AP-1000. Both have continuing challenges in terms of production and deployment, and the reactors are not a standard line of business for Brookfield Renewable Partners.

Westinghouse has been actively promoting its various reactor designs internationally, especially in Europe, including in Bulgaria, the Czech Republic, Poland, and Ukraine.

Korea Electric Power Corporation (KEPCO)

KEPCO is majority publicly-owned, with 32.9 percent ownership by the Korea Development Bank and 18.2 percent ownership by the Government of Korea as of the end of 2022.[1755] The

1750 - Fitch Ratings, "Rating Report: China General Nuclear Power Corporation", 5 January 2023, see https://www.fitchratings.com/research/corporate-finance/china-general-nuclear-power-corporation-05-01-2023, accessed 27 September 2023.

1751 - Yahoo Finance, as of 30 September 2023.

1752 - Tom Hals, "Toshiba reaches $2.2 billion deal over SCANA's South Carolina nuclear project", *Reuters*, 27 July 2017, see https://www.reuters.com/article/us-toshiba-accounting-westinghouse-scana/toshiba-reaches-2-2-billion-deal-over-scanas-south-carolina-nuclear-project-idUSKBN1AC3DN, accessed 27 September 2023.

1753 - Squire Patton Boggs, "CFIUS Clearance: Brookfield Business Partners L.P. and Westinghouse Electric Company", 1 June 2023, see https://www.lexology.com/library/detail.aspx?g=7130ceab-2649-4d24-803b-85dc69aea11b, accessed 27 September 2023.

1754 - Antoine Gara and Myles McCormick, "Westinghouse to be sold for $7.9bn in sign of nuclear power revival", *Financial Times*, 11 October 2022, see https://www.ft.com/content/46df2aa9-0963-47a6-881c-f715a18a8527, accessed 20 September 2023.

1755 - KEPCO, "Shareholder structure of Korea Electric Power Corp. as of December 31, 2022", Korea Electric Power Corporation, see https://home.kepco.co.kr/kepco/EN/C/htmlView/ENCCHP003.do?menuCd=EN030303, accessed 27 September 2023.

KEPCO Act requires state ownership of at least 51 percent of the corporation, and shareholder rights by both state owners are "exercised by the Ministry of Trade, Industry and Energy in consultation with the Ministry of Economy and Finance."[1756] Nuclear activities are primarily conducted within the Korea Hydro & Nuclear Power (KHNP) subsidiary.

Coal continues to be the largest share of generating assets owned by KEPCO, though nuclear is second and has grown from 34 percent of assets in 2012 to 38 percent in 2021.[1757] The firm's operating margin has been hurt by high and volatile coal and LNG prices, with operating losses in four of the past five years.[1758] Operating losses in 2022 were nearly US$25 billion, the largest ever. The utility had been restricted from increasing rates by the government and claims its electricity prices are half those in Japan—which, by international standards, are themselves very high.[1759]

One result was surging debt, which hit 200 trillion Won (US$149 billion) for the first time in its history and approaching the limits of its bond issuing capacity.[1760] Losses within KHNP were over 1 trillion Won (US$763 million) on sales of 4 trillion Won (US$3 billion) during the first half of 2023.[1761] Five price increases were allowed in 2023 and have helped to stabilize revenues.

KEPCO's debt levels would unlikely be supportable were it a private company. With majority state ownership, "KEPCO has benefited from the sovereign ratings umbrella and received a rating that is six to eight notches higher than its baseline credit assessment, despite having difficulties with cash flows and debt service. This has enabled KEPCO to have good financing options despite weak underlying financial fundamentals."[1762] Credit rating firm Fitch notes that the ratings on KEPCO are equal to those of the state (AA-/Stable) "under Fitch's Government-Related Entities (GRE) Rating Criteria, reflecting a very strong likelihood of government support."[1763]

Constellation Energy Corporation

Constellation Energy (ticker CEG) is the largest operator of nuclear power plants in the U.S. It was created through a tax-free spinoff of the power generation business out of Exelon, which took effect in February 2022. While some regulated generation transmission and distribution

1756 - KEPCO, "Form 20-F", filing to the US Securities and Exchange Commission, Korea Electric Power Company, 29 April 2023, see https://www.sec.gov/Archives/edgar/data/887225/000119312523124899/d427740d20f.htm, accessed 27 September 2023.

1757 - Christina Ng and Hazel James Ilango, "KEPCO's Clean Energy Transition Hangs in the Balance", Institute for Energy Economics and Financial Analysis, October 2022, p.3, see https://ieefa.org/media/3291/download?attachment, accessed 27 September 2023.

1758 - Ibidem, p. 6.

1759 - Kotaro Hosokawa, "South Korean politics tie KEPCO's hands on electricity rate hikes", *Nikkei Asia*, 23 April 2023, see https://asia.nikkei.com/Business/Energy/South-Korean-politics-tie-KEPCO-s-hands-on-electricity-rate-hikes, accessed 27 September 2023.

1760 Jung Suk-yee, "KEPCO Debt Surpasses 200 Trillion Won for First Time in History", *Business Korea*, 23 August 2023, see https://www.businesskorea.co.kr/news/articleView.html?idxno=200147, accessed 27 September 2023.

1761 KEPCO, "Korea Electric Power Corporation and Its Subsidiaries, Interim Consolidated Financial Statements - For the six-month periods ended June 30, 2023 and 2022", Korea Electric Power Company, 11 September 2023, p. 47, September 2023.

1762 - IEEFA, "KEPCO's Clean Energy Transition Hangs in the Balance", October 2022, op. cit. p. 9.

1763 - Fitch, "Fitch Affirms KEPCO at 'AA-'; Outlook Stable", 19 June 2023, see https://www.fitchratings.com/research/corporate-finance/fitch-affirms-kepco-at-aa-outlook-stable-19-06-2023, accessed 27 September 2023.

assets remained within Exelon (EXC),[1764] all of Exelon's nuclear assets were spun into the new company. CEG includes many non-nuclear generation assets as well. Both are private firms.

Constellation controlled more than 20 percent of net summer U.S. nuclear capacity in 2019.[1765] WNISR calculations indicate nearly 40 percent of its reactors (comprising nearly 1/3 of its production capacity) received state support as of 2021.[1766] Further, of the twelve reactors receiving targeted state (subnational) support to nuclear power in 2021, nine were owned by Constellation. State subsidies are a significant contributor to returns on Constellation's nuclear business.

Tokyo Electric Power Company (**TEPCO**) (ticker 9501.T)

The Government of Japan has held a majority stake in TEPCO since the firm's impending collapse soon after the Fukushima accident in March 2011. The government has targeted a profit margin of ¥450 billion (US$$_{2023}$3 billion) as part of the reconstruction plan, but the utility has fallen short in recent years. In 2022, TEPCO experienced its first net loss in a decade and was unable to fund its annual contribution to a victim's fund.[1767] The firm needed US$3 billion in emergency loans from a consortium of banks in early 2023 to help stabilize the utility in the face of surging fuel prices and a weakening Yen.[1768]

Not surprisingly, TEPCO's stock price fell more than 80 percent following the accidents in March 2011, reaching its lowest-ever price of 362 Yen in April 2011 as information emerged on radiation leakage.[1769] Recent performance has been better, with the share price more than doubling since December 2021, though remaining less than one-third its pre-Fukushima level.[1770]

Cleanup challenges remain daunting. During 2023, the first batch of radioactive wastewater from Fukushima was being released into the sea despite public and international opposition and commercial concerns about markets for Japanese seafood. Decommissioning the Fukushima Daiichi plant has "barely progressed" and removal of the melted nuclear fuel has not started (see Fukushima Status Report). Estimates on the costs to deal with the accident cleanup costs and victim compensation continue to rise. WNISR2017 noted a doubling of estimates in 2016 to ¥22 trillion (US$220 billion).[1771] In 2019, a private think tank, the Japan Center for

1764 - Joe Cornell, "Exelon Completes Spin-Off of Constellation Energy", *Forbes*, 3 February 2022, see https://www.forbes.com/sites/joecornell/2022/02/03/exelon-completes-spin-off-of-constellation-energy/, accessed 20 September 2023.

1765 - NEI, "U.S. Nuclear Plant Owners and Operators", Nuclear Energy Institute, Updated July 2023, see https://www.nei.org/resources/statistics/us-nuclear-plant-owners-and-operators, accessed 20 September 2023.

1766 - Mark Holt and Phillip Brown, "U.S. Nuclear Plant Shutdowns, State Interventions, and Policy Concerns", CRS Report R46820, Congressional Research Service, Updated 7 February 2022, see https://crsreports.congress.gov/product/pdf/R/R46820/6, accessed 21 July 2023.

1767 - *Asahi Shimbun*. "EDITORIAL: TEPCO yet again fails to deliver, this time it can't afford redress", 12 May 2023, see https://www.asahi.com/ajw/articles/14906171, accessed 20 September 2023.

1768 - Jun Watanabe, "Japan's TEPCO to receive $3bn in emergency loans from top lenders", *Nikkei*, 15 February 2023, see https://asia.nikkei.com/Business/Energy/Japan-s-TEPCO-to-receive-3bn-in-emergency-loans-from-top-lenders, accessed 20 September 2023.

1769 - *BBC News*, "Tepco shares plunge to record low on radiation crisis", 5 April 2011, see https://www.bbc.com/news/business-12968812, accessed 20 September 2023.

1770 - *Yahoo! Finance*, "Tokyo Electric Power Company Holdings, Incorporated", 2023, see https://finance.yahoo.com/quote/9501.T?p=9501.T&.tsrc=fin-srch, accessed 27 September 2023.

1771 - Yuka Obayashi, "Japan urges bold reform for Tepco as Fukushima costs soar", *Reuters*, 20 December 2016, see http://www.reuters.com/article/us-tepco-fukushima-reform-idUSKBN14911V, accessed 25 June 2017.

Economic Research, said that compensation, decommissioning, and decontamination costs were expected to reach ¥41 trillion (US$283 billion) for a scenario in which Fukushima water was diluted and discharged into the sea.[1772] As of June 2023, the amount paid out by TEPCO in compensation alone totaled already 10,817 billion yen (US$$_{2023}$77.5 billion).[1773]

Litigation over the accident continues. A case brought by shareholders led to a 2022 civil court ruling of US$95 billion in liability for four former TEPCO executives for damages associated with the Fukushima accident—the first time a court had found top executives liable.[1774] Courts in 2019 found executives not criminally liable in the accident.[1775] This was upheld by the Tokyo High Court in 2023.[1776]

State support and private investments into advanced reactors

Private-sector investments in nuclear are up, with private equity and venture capital deals related to nuclear power quadrupling between 2015 and 2022 based on Pitchbook, which tracks private equity markets.[1777] How are these deals structured, and how does this trend align with increasing reliance on government subsidies and ownership within the nuclear sector? A few factors are at play.

First, the investments are starting from a very small base, so the private fund flows into the higher risk sectors (as opposed to, for example, traditional utility investments in nuclear power) are still quite small.

Second, there are higher- and lower-risk segments of the industry. For example, a recent private equity fund announced by Pelican Energy Partners aims to take its expertise in oilfield services and apply them to nuclear energy services.[1778] These areas may be complicated, but there are established businesses and standard business practices to manage them. Pelican recently invested in a firm providing software to the nuclear industry.[1779] The US$7.9 billion deal to purchase Westinghouse Electric by Brookfield Renewable Partners and Cameco also had a significant service component. Brookfield, the majority owner, highlighted that "Westinghouse,

1772 - Kiyoshi Takenaka, "More nuclear challenges await Japan after Fukushima water release", *Reuters*, 24 August 2023, see https://www.reuters.com/world/asia-pacific/more-nuclear-challenges-await-japan-after-fukushima-water-release-2023-08-24/, accessed 27 September 2023.

1773 - TEPCO, "Baisho Kin no Oshiharai Jokyo" ["Current status of Compensation paid so far"], Tokyo Electric Power Co Holdings, 23 June 2023 (in Japanese), see https://www.tepco.co.jp/fukushima_hq/compensation/images/jisseki01-j.pdf, accessed 26 June 2023.

1774 - *Reuters*, "Tokyo court orders ex-Tepco execs to pay $95 bln damages over Fukushima disaster", as published on *CNN Business*, 13 July 2022, see https://www.cnn.com/2022/07/13/business/tokyo-court-fukushima/index.html, accessed 27 September 2023.

1775 - Mari Yamaguchi, "Japan court: TEPCO execs not guilty in Fukushima disaster", *The San Diego Union-Tribune*, 19 September 2019, see https://www.sandiegouniontribune.com/business/nation/story/2019-09-18/japan-court-to-rule-on-tepco-execs-nuclear-crisis-liability, accessed 27 September 2023.

1776 - Tom Bateman and Sakura Murakami, "Tokyo court upholds not guilty verdict for ex-Tepco execs over Fukushima disaster", *Reuters*, 18 January 2023, see https://www.reuters.com/world/asia-pacific/tokyo-court-upholds-not-guilty-verdict-ex-tepco-execs-over-fukushima-disaster-2023-01-18/, accessed 27 September 2023.

1777 - Benton Arnett, "Nuclear on Wall Street - The Talk of the Town", NEI Blog, Nuclear Energy Institute, 10 March 2023, see https://www.nei.org/news/2023/nuclear-on-wall-street-the-talk-of-the-town, accessed 7 June 2023.

1778 - Pelican Energy Partners, "Focused on the long-term fundamentals", Undated, see https://www.pelicanenergypartners.com/nuclear-service-strategy, accessed 28 September 2023.

1779 - Pelican Energy Partners, "Pelican Energy Partners Announces Partnership with Blue Wave AI Labs", as published on *CISION PR Newswire*, 26 June 2023, see https://www.prnewswire.com/news-releases/pelican-energy-partners-announces-partnership-with-blue-wave-ai-labs-301862766.html, accessed 28 September 2023.

a Brookfield portfolio company, serves as the core service provider for over 50% of the world's 440 operating reactors.[1780] The company pioneered the commercial nuclear power industry and is the original equipment manufacturer for half of the world's nuclear fleet."[1781]

Westinghouse also has significant reactor technology assets, many of which face regulatory and technology risks that are quite different from more traditional service business. The risks of these two segments should be expected to be very different. Perspectives on these differences can be garnered through private investments in stand-alone reactor companies such as TerraPower.[1782]

Joe Lassiter of Harvard Business School notes that for conventional "clean-tech" investments, there is a high level of risk similar to that of biotech or new pharma. Investors expect a high failure rate, with very high returns on the few that succeed. Early-stage investors participate in multiple deals to diversify risk, and each stage brings in new investors. Using the pharma example, funding stages generally occur at key milestones, such as when drug efficacy and regulatory hurdles are met (or not), affecting the company's valuation at that round. There is an expectation of some government support in these areas, particularly at the research stage.

The investing pattern in new- build fission (and fusion) ventures differs in important respects from either biotech or conventional clean tech. First, the radioactive and special nuclear materials being used mean that nearly all activity requires high levels of government oversight and reporting. Testing of all prototypes also needs government approval on both the technology and the siting.

While incumbent firms and utilities do invest in conventional reactor projects, few private equity and venture capital investors have chosen to fund the new reactor segment of the nuclear sector, whether conventional or advanced. One of the funds that has chosen to get involved is Nucleation Capital, which includes advanced nuclear as a core focus area and aims to make the deals accessible for smaller investors. Another is Intellectual Ventures (IV), which housed TerraPower from its initial startup. There was strong support for the concept from IV founder Nathan Myhrvold, as well as from investor Bill Gates.

The company provides a useful case study of private capital in the nuclear sector. After being spun out of IV, the company received additional capital from Gates, as well as from additional investors. The initial rounds of TerraPower were funded by wealthy individuals seeking not just a financial return, but a societal one as well. Financial returns have been the central driver for later investors, which included other wealthy individuals and a few venture funds in the next funding round, followed by foreign high-net-worth investors and sovereign wealth funds. Corporate partners such as the SK Group, one of South Korea's largest energy providers, also invested.[1783] Co-investments from firms benefiting from the reactor or related technologies if

1780 - As of mid-2023, there were 407 operating reactors in the world (see General Overview).

1781 - Brookfield, "Transition Investing: A New Dawn for Nuclear Power", *Insights*, September 2022, see https://www.brookfieldoaktree.com/sites/default/files/2023-04/Brookfield_Nuclear_Power_September_2022.pdf, accessed 7 June 2023.

1782 - We are grateful to Joe Lassiter at Harvard Business School for his insights into this part of the business, an area of research for him. Correspondence was with Doug Koplow by phone and email in May and September 2023. Any errors or omissions are our responsibility.

1783 - TerraPower, "TerraPower Announces $750 Million Secured in Fundraise", Press Release, 15 August 2022, see https://www.terrapower.com/fundraise/, accessed 28 September 2023.

the companies are successful have been a feature of a number of these ventures, including NuScale and X-energy, discussed below.

Lassiter noted that the target exit for a firm such as TerraPower would be through successful licensing, and potentially by completing one or two operating projects. In this sector, the private investors assume a high level of government support throughout all funding rounds. The mix and scale of policy support, direct funding and research partnerships, and financial de-risking are important inputs into the private funding decisions.

While pharmaceutical and biotech funds have target internal rates of return above 20 percent, Lassiter said the investors in advanced nuclear view their investments as a lottery ticket that gives them the right to participate or withdraw based on the results of initial stages. Most likely they will lose, but if they win, the returns could be enormous. They also try to diversify across projects to the extent possible, given the much smaller breadth of the advanced nuclear sector relative to venture-funded pharma and biotech.

In addition to Lassiter's insights, it is notable that two SMR companies have tried to go public in the U.S. well before the operating project stage. NuScale (ticker SMR) is now publicly traded but has seen its stock price drop by over 80 percent between August 2022 and mid-November 2023. The firm's market capitalization as of mid- November 2023 was just under US$185 million.

X-energy planned to go public using a business combination with the Ares Acquisition Corporation (ticker AAC) as a Special Purpose Acquisition Company (SPAC). Announced in December 2022, the planned merger was terminated by both parties at the end of October 2023. The companies cited "challenging market conditions, peer-company trading performance and a balancing of the benefits and drawbacks of becoming a publicly traded company under current circumstances" in the decision.[1784] X-energy will continue as a privately-held corporation. The U.S. Department of Energy has committed to invest US$1.23 billion in the firm's reactor through its Advanced Reactor Development Program.[1785]

CONCLUSIONS

Reflecting the image of a nearly continuous, low-carbon source of electricity, nuclear power is seen as a central strategy to decarbonize economies in many national and international scenarios. Achieving these targets on a capacity basis requires a doubling or more of nuclear capacity—and far more to achieve on a net-of-retirements basis, as even with license extensions, many older reactors will have closed by 2050.

Despite optimistic numerical targets for expansion, the proposed role for nuclear power in a decarbonized world faces continued competitive pressures on both cost and technical capabilities. This includes the economics of operating reactors and the funding of new ones.

1784 - X-energy Corporation, "X-energy and Ares Acquisition Corporation Mutually Agreed to Terminate Business Combination Agreement", Press Release, 31 October 2023, see https://x-energy.com/media/news-releases/x-energy-ares-mutually-terminate-business-agreement, accessed 7 November 20230.

1785 - Dan Yurman, "X-Energy Signs on to DOE ARDP for $80M in Initial Funding", *Neutron Bytes*, 7 March 2021, see https://neutronbytes.com/2021/03/07/x-energy-signs-on-to-doe-ardp-for-80m-in-initial-funding/, accessed 28 September 2023.

Costs falling fast for nuclear competitors, increase for nuclear. Between 2010 and 2021, the global weighted average Levelized Cost of Energy (LCOE) for utility PV fell by 90 percent; for concentrating solar and onshore wind by 70 percent, and for offshore wind by 60 percent, according to IRENA.[1786] Lazard's U.S.-focused analysis of LCOE shows significant declines between 2009 and early 2023 with 83 percent for utility-scale solar and 63 percent for onshore wind; in contrast, the LCOE for nuclear power has *risen* 47 percent over the same period.[1787] Both Lazard and Bloomberg New Energy Finance typically show new-nuclear LCOE several to many times higher than for unsubsidized solar PV and wind power, and this gap is widening.

Forward-looking LCOE estimates for nuclear likely understate costs due to a number of favorable assumptions.

First, they generally assume the same cost of capital as applied to technologies that require smaller capital investments, have far shorter lead times, depend less if at all on government subsidy, offer greater cost and delivery time certainty, and have more attractive risk profiles for investors.

Second, capital costs embed *n*th-of-a-kind (NOAK) learning curves that are speculative and more optimistic than what the nuclear industry has experienced over the past sixty years. It has not yet demonstrated a learning curve in any sustained program, while solar PV, wind power, and lithium-ion batteries exhibit strong learning curves sustained over decades and with strong evidence of continuing.

Third, long-term aspects of the nuclear fuel chain that are both challenging and expensive have been partially or entirely socialized and are therefore underestimated in, or entirely left out of, LCOE calculations. This includes liability for accident risks, site decommissioning costs, and long-term management of high-level nuclear wastes. All of these factors result in nuclear LCOEs that are lower and more competitive than the reality of the nuclear fuel chain.

A meta-analysis of 88 reactor projects found a striking difference between cost projections and those tabulated from actual completed projects. Build times for recent and ongoing projects within OECD countries were 10–17 years versus projected construction periods of only 5–9 years.1788 Median projected costs were US$5,122/kW costs versus US$9,250/kW median (+80 percent) for actual costs incurred.[1789] The use of overly optimistic cost projections contributes to overstating penetration rates of nuclear in cost optimizing energy system models. Reliable data were not available to develop similar assessments outside the OECD.

Nuclear LCOE data were available from multiple assessments for 2020–2022 and varied from US$51/MWh to US$158/MWh depending on estimator (see Table 22). In part this reflects different assumptions about the cost of capital. However, variation in overnight construction cost estimates (excluding financing costs) were also significant, though the reasons behind the shifts (sometimes done by the same organization) were less clear. This level of variation

1786 - IRENA, "Renewable Power Generation Costs in 2021", International Renewable Energy Agency, July 2022, p.15, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf?rev=34c22a4b244d434da0accde7de7c73d8, accessed 21 July 2023.

1787 - Lazard, "LCOE+", April 2023, op. cit., p.9.

1788 - DIW and WIP, "Economics of Nuclear Power in Decarbonized Energy Systems", Preprint, 14 March 2023, op. cit., p. 3.

1789 - Ibidem.

illustrates the uncertainty with nuclear cost projections, though the real values, and investors' perceptions of their riskiness, will drive when or whether nuclear will be able to compete with alternative decarbonization pathways.

Much lower nuclear LCOE estimates come out of China, Russia, India, and South Korea. Analysts point out limitations on cost transparency in these countries, and significant state involvement with the full nuclear fuel chain in both China and Russia, in reducing confidence in the reported figures. They also point to construction and management techniques that could be useful to adopt in nuclear and other complex projects worldwide. Particularly in China, despite lower nuclear build costs than in the U.S. and E.U., wind and solar costs are lower still, resulting in competitive dynamics that remain challenging for nuclear newbuild. And despite China's low labor costs, its world-leading nuclear program is out-generated and far out-invested individually by solar PV and by wind power.

Declining costs more likely to continue for nuclear competitors. The number of new installations of wind turbines, PV cells, and batteries of all types is already many orders of magnitude higher than for nuclear reactors, and even with aggressive growth targets for nuclear, will remain so. The scale of installations offers a much greater opportunity for incremental learning, cost reductions, and co-development of multiple formulations and technologies. Installations of utility scale battery storage have accelerated from a base of only 0.3 GW in 2015 to new installations of more than 11 GW in 2022.[1790] Notably, this is more than the 7.4 GW of net new nuclear capacity connected to the grid that year.

These trends pose a challenging competitive barrier for newbuild nuclear. Long-term contracts pairing solar with storage to reduce the variable element of renewable energy are already common and often competitive, such as a 25-year contract by the Los Angeles Board of Water and Power for a price of US$3.96 cents/kWh and other power purchase agreements in recent years, similar to the operating costs of existing well-performing nuclear reactors but below operating cost for many around the world and largely below total newbuild costs for all.[1791]

The traditional utility model built on large thermal plants operating nearly continuously to spread fixed costs is coming under major challenge from a diverse portfolio of ways to use electricity more efficiently and to balance grid supply and demand on a variety of timescales. With this flexibility, old assumptions about needing massive electricity storage capacity to keep the grid reliable as it becomes renewable may also break down. Other methods show increasing evidence of achieving the same or better reliability and resilience with little or no bulk storage and at lower system cost. For example, simulations show the isolated Texas grid in 2050 could run without bulk storage, and South Australia's GW-scale grid, which does use bulk storage, just ran for a year 71.5 percent powered by sun and wind. It is officially forecast to reach 100 percent renewable in 2026–2027, and already has generally

1790 - IEA, "Annual grid-scale battery storage additions, 2017-2022", International Energy Agency, Updated 10 July 2023, see https://www.iea.org/data-and-statistics/charts/annual-grid-scale-battery-storage-additions-2017-2022, accessed 7 August 2023.

1791 - Sammy Roth, "Los Angeles OKs a deal for record-cheap solar power and battery storage", *Los Angeles Times*, 10 September 2019, see https://www.latimes.com/environment/story/2019-09-10/ladwp-votes-on-eland-solar-contract, accessed 28 August 2023; and Mark Bolinger, Joachim Seel et al., "Utility-Scale Solar, 2023 Edition", Lawrence Berkeley National Laboratory, October 2023, p. 49, see https://emp.lbl.gov/sites/default/files/utility_scale_solar_2023_edition_slides.pdf, accessed 14 November 2023.

operated at 100+ percent renewables in the daytime.[1792] Now that one in every five PV modules is on a Chinese roof,[1793] a new generation of simulation models is needed to ensure that the full slate of generating options, including distributed ones, are properly combined with demand-side and all other grid-balancing resources. Hundreds of peer-reviewed analyses simulating fully-renewable power supply suggest that the legacy models still informing most government policies inadequately integrate new ways of reliably running and balancing power grids .[1794]

New markets for nuclear face some common challenges to competitive growth. Frequently-mentioned areas of future growth for nuclear include production of hydrogen, water desalination, high temperature heat, and power for industrial production, and dedicated use for remote locations or high-demand applications such as data centers. These applications require cost-competitive power. Unless newbuild nuclear can achieve large cost reductions, this will be unlikely.

Efforts to use surplus power from existing nuclear to support these markets is attractive since the power costs from existing reactors is lower, and there is excess supply during some periods of the day. However, because the industrial users require highly reliable deliveries to keep production orderly, efficient, and competitive, either a dedicated reactor or a 24/7 slice of reactor production would be needed. This would put these other uses in competition with current grid users for low-carbon electricity rather than increasing the overall supply. Particularly where market diversions are driven by government subsidy (perhaps the case with hydrogen in the U.S.) rather than economic value, both system costs and carbon emissions could rise.

State subsidies and ownership play an increasing role in nuclear power worldwide. In the face of continued economic headwinds, state involvement with the nuclear industry has continued to grow. The nuclear industries of both China and Russia are extensions of the state with large amounts of government support that is often challenging to quantify. Russian activities have been somewhat, but not largely, constrained after the invasion of Ukraine. China and Russia continue to gain market share in reactor construction and operation. Russia and its allies continue to dominate uranium mining and enrichment as well as nuclear fuel assembly manufacturing, sectors that also include other governments as well with little residual private activity. Increasing levels of subsidized sovereign credit from Russia and China have been used to spur nuclear projects abroad. OECD countries have also provided cheap export credit for nuclear services and equipment and are starting to commit to new construction as well, particularly for SMRs. Market economics play little part in these trends.

For domestic projects, a number of U.S. states have introduced special payments to subsidize nuclear production at many existing reactors (see United States Focus), many owned by Constellation Energy, the country's largest nuclear plant owner. The stated goal of these policies is to protect a zero-carbon, firm source of electricity; these states currently do not have a material price on carbon. Federal tax credits and other special subsidies have been introduced

1792 - Giles Parkinson, "Wind and solar average stunning 87 pct of South Australia's demand over month of October", RenewEconomy, 2 November 2023, see https://reneweconomy.com.au/wind-and-solar-meet-stunning-87-pct-of-south-australias-demand-over-month-of-october/, accessed 6 November 2023.

1793 - *Bloomberg News*, "China Takes Its Climate Fight to the Rooftops", 27 March 2023, see https://www.bloomberg.com/news/features/2023-03-27/why-china-rooftop-solar-power-leads-world-on-clean-energy-capacity?leadSource=uverify%20wall, accessed 14 November 2023.

1794 - Amory Lovins, "US nuclear power: Status, prospects, and climate implications", *The Electricity Journal*, May 2022, op.cit.

as well. Whether reactors are able to double-dip at the state and federal levels is not yet clear, but the federal support undoubtedly extends the geographic reach of subsidies to operating reactors. The U.K. has continued both direct investments and de-risking of private nuclear investments through price floors and guaranteed returns for new reactor projects. TEPCO, the largest nuclear utility in Japan, has remained nationalized since the Fukushima accident, with taxpayers bearing growing liabilities to address damages and victim compensation. EDF, the world's largest nuclear operator, was renationalized by the French government in 2022 due to rising debts and operating problems. Debt levels remain high, and taxpayers are likely to be the source of funds for planned new build reactors, elevated maintenance on the existing fleet, and plant closure costs that are significantly underprovisioned in comparison to peers.

After a bankruptcy due to large cost overruns on U.S. projects, Westinghouse seems on be on firmer footing, now owned by a consortium of Brookfield, a Canadian private equity asset manager, and Cameco, a uranium mining and processing firm. Reactor development and construction is a new business for both, however. KEPCO, South Korea's largest utility, incurred large losses in 2022 and holds record debt levels. It is majority government-owned, allowing it better terms on interest rates and debt levels, but remains on a precarious footing. Globally, governments have stepped in to bear many, most, or all (depending on the country) of the risks for nuclear accidents, high-level waste management, and plant and fuel chain facility decommissioning. Alternative decarbonization pathways lack similar attributes but are competitively disadvantaged.

Even with pervasive subsidies (often referred to as "policy support" in international assessments), it will be a challenge for newbuild nuclear to be competitive. There are widely disparate estimates on how many reactors or reactor modules are needed to move from first-of-a-kind (FOAK) to nth-of-a-kind (NOAK) values already cooked into most of the models. As more reactor types from more companies compete for those same installations, achieving NOAK for each becomes more challenging if not impossible. Market actors will almost certainly require higher returns on nuclear investments than those in other areas, with compounding over a longer delivery cycle worsening nuclear's market positioning.

Achieving low-cost, expedited carbon reduction through the nuclear pathway will be challenging. Further, there is the added concern regarding how quickly nuclear resources can be scaled—including with SMRs. Being low-carbon is not enough. The speed and unit cost of abatement are both critical attributes in reducing greenhouse gas emissions in a relevant time frame, and carbon reductions sooner are more valuable than carbon reductions decades in the future. New reactor technologies that also require changes to fuel production and waste management are estimated by the U.S. National Academies of Science, Engineering and Medicine to take 50 to 100 years.[1795] Some of these new fuels increase weapons proliferation risks, an important issue rarely discussed by nuclear power proponents. Even new reactors without associated fuel-chain changes face significant challenges to scale. The delivery and cost risks here were deemed sufficiently worrying for the U.S. National Academies to flag them, arguing that the U.S. Department of Energy needed to select just a few designs to increase

1795 - NASEM, "Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors", National Academies of Sciences, Engineering, and Medicine, 2023, p.54, see https://doi.org/10.17226/26500, accessed 21 July 2023.

the chances it could move them to deployment by 2050.[1796] As 2050 is also the target date for economies to be net zero carbon under many of the climate stabilization plans, starting deployment of reactors at that point or later will miss the critical decarbonization period.

Overall, the economic headwinds for nuclear will remain challenging. Research and deployments will rely primarily on government money, absorption of risks, and direct ownership. Even "private" reactor projects will operate in heavily government-supported environments. In the broader energy marketplace, it is likely that by the time cost improvements could occur, technological developments in competing generating technologies, energy storage, demand side management, and energy efficiency will have moved the economic costs down still further and the reactors will remain too costly. No-regrets policies such as putting an appropriate price on carbon would help nuclear economics as well as other decarbonization pathways, though in a more market-neutral way than most of the current "policy support".

1796 - Ibidem, p.54.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

INTRODUCTION

2022 and 2023 are already seen as pivotal years for the development of the global energy sector, as the impacts of climate change, along with Russia's continued war of aggression in Ukraine, maintain the focus on the sustainability and stability of the global industry.

Russia's invasion of Ukraine has had a complex and varied impact on the global energy sector. The consulting group McKinsey stated in the Spring of 2022 that "the war will complicate the transition's path in the short term. In the longer term, however, energy security and economics logic could converge to kick net-zero transition efforts into higher gear."[1797] Europe, particularly the E.U., was an example of a region where more significant concerns over energy security led to accelerated decarbonization, with raised targets for Greenhouse Gases (GHG) emissions reduction, energy efficiency, and renewable energy deployment. However, the scale of investment in Liquified Natural Gas (LNG) infrastructure justifiably raised concerns over locking in future fossil fuel use and, consequently, CO2 emissions. At the same time, higher energy prices increased the profits of fossil fuel producers. Global Witness analyzed the 2022-profits of the five largest integrated private sector oil and gas companies: Chevron, ExxonMobil, Shell, BP, and TotalEnergies. Their profits add up to US$195 billion, an increase of almost 120 percent over the previous year and "the highest level in the industry's history".[1798] At the same time, Saudi Aramco reported a record net income of US$161.1 billion in 2022—its "highest annual profits as a listed company."[1799] The higher profits support the budget in the countries with National Oil Companies and the shares and dividends of the investors and pension funds of the International Oil Companies, giving them more significant financial and political support, leading to some companies slowing down their commitments to reduce emissions.

In addition to, and to some extent in response to these, new domestic industrial and economic strategies are being implemented to secure domestic manufacturing and supply chains for the energy transition. This has been driven by the need to stimulate domestic manufacturing in sectors with longer term futures—such as renewable energy or electric vehicles—and in response to increased awareness of overdependency on some countries, given increasing geopolitical instability. Adopting the Inflation Reduction Act (IRA) in the U.S. in August of

1797 - Hamid Samandari, Dickon Pinner et al., "McKinsey Quarterly—The net-zero transition in the wake of the war in Ukraine: A detour, a derailment, or a different path?", McKinsey Sustainability, 19 May 2022, see https://www.mckinsey.com/capabilities/sustainability/our-insights/the-net-zero-transition-in-the-wake-of-the-war-in-ukraine-a-detour-a-derailment-or-a-different-path, accessed 17 September 2023.

1798 - Global Witness, "Crisis year 2022 brought $134 billion in excess profit to the West's five largest oil and gas companies", 9 February 2023, see https://www.globalwitness.org/en/campaigns/fossil-gas/crisis-year-2022-brought-134-billion-in-excess-profit-to-the-wests-five-largest-oil-and-gas-companies/, accessed 17 September 2023.

1799 - Aramco, "Aramco announces record full-year 2022 results", 12 March 2023, see https://www.aramco.com/en/news-media/news/2023/aramco-announces-full-year-2022-results, accessed 5 July 2023.

2022 had a cascading effect on legislation worldwide as international companies threatened to move manufacturing to take advantage of production subsidies and tax breaks[1800].

The U.S. IRA has not been universally welcomed as many countries saw it threatening their decarbonization plans. However, Fatih Birol, the Executive Director of the OECD's International Energy Agency (IEA), welcomed it as the most significant climate agreement since the signing of the Paris Agreement in 2015 and a turbo charge to the energy transition.[1801] Others are less positive towards the legislation, with French President Emmanuel Macron reportedly calling the IRA "super aggressive" toward European companies.[1802]

However, while the extent to which companies and governments continue to debate the use of fossil fuels, the fortunes of non-fossil energy sources continue to move in different directions. As shown in this chapter, the main area for optimism for a secure and sustainable energy system—together with remarkable progress on sufficiency and efficiency—is renewable energy development, whose pace of development and deployment continues to accelerate. While in contrast, nuclear power remains, at best marginal and all too often irrelevant to the challenges ahead.

INVESTMENT

Figure 62 compares the annual investment decisions for constructing new nuclear plants with those for renewable energy since 2004. The investments presented relate only to construction cost-estimates at the start of the project and therefore will not take into consideration any subsequent increases, which in the case of nuclear power can be considerable. Furthermore, these figures do not include any costs associated with the decommissioning of any facility or waste management. Throughout this section "new renewables" refers to solar (PV and concentrated solar), wind (onshore and offshore), bio-based energy sources, marine and geothermal sources. The only renewable energy source that is excluded, is large scale hydro.

As in 2021, construction began on ten reactors in 2022: five reactors in China, two in Egypt, one in Turkey, along with a new floating power station for Russia (which contains two 55 MW reactors). The total reported and estimated investment for the construction of the 2022 projects is around US$35.1 billion for 9.4 GW. During 2022, the total investment in non-hydro renewables globally was a record US$495 billion of which the individual investments in wind and solar were US$174 billion and US$307 billion respectively.[1803] REN21 concludes that investment in the power sector in 2022 was 74 percent renewables, up from 69 percent the previous year, 19 percent fossil fuels and 8 percent nuclear, the same level as coal.

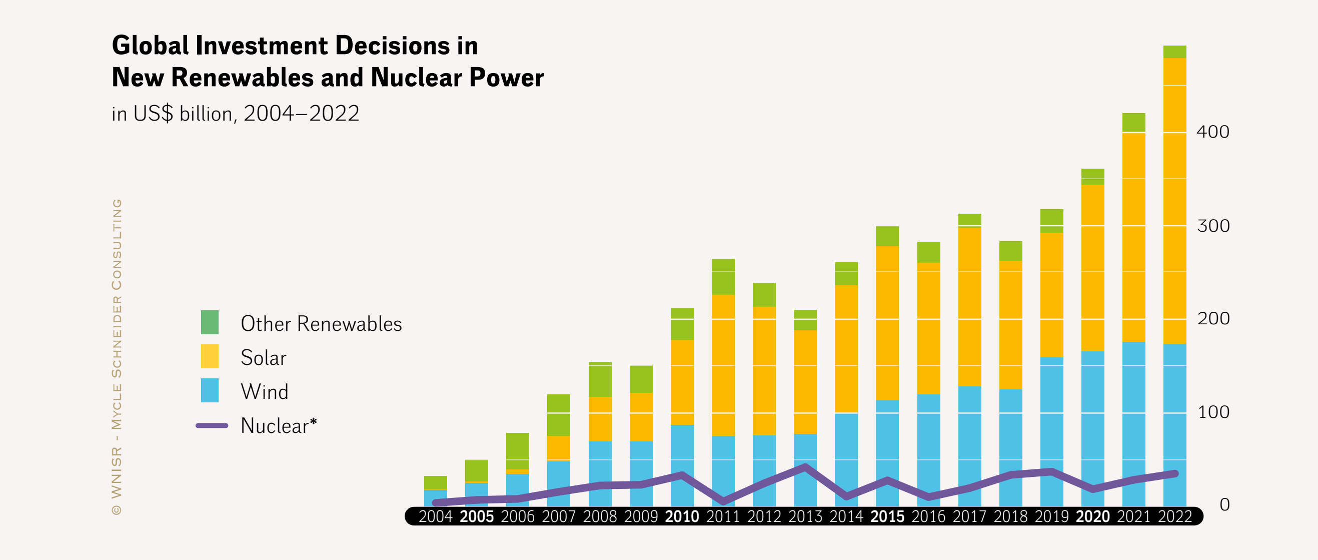
1800 - Eva Mathews, Sinchita Mitra and Prerna Bedi, "How companies are reacting to the U.S. Inflation Reduction Act", *Reuters*, 24 February 2023, see https://www.reuters.com/markets/company-reaction-us-inflation-reduction-act-2023-02-23/, accessed 17 September 2023.

1801 - Sam Meredith, "IEA chief lauds U.S. Inflation Reduction Act as most important climate agreement since Paris accord", *CNBC*, 17 January 2023, see https://www.cnbc.com/2023/01/17/iea-chief-says-ira-most-important-climate-agreement-since-paris-accord.html, accessed 17 September 2023.

1802 - Michel Rose and Jeff Mason, "U.S. Inflation Reduction Act 'super aggressive,' Macron tells lawmakers", *Reuters,* 1 December 2022, see https://www.reuters.com/world/europe/macron-visits-nasa-talks-space-cooperation-us-visit-begins-2022-11-30/, accessed 17 September 2023.

1803 - REN21, "Renewables 2023 Global Status Report—Energy Supply", 2023, see https://www.ren21.net/wp-content/uploads/2019/05/GSR-2023_Energy-Supply-Module.pdf, accessed 5 July 2023.

Figure 62 · Global Investment Decisions in Renewables and Nuclear Power, 2004–2022



Sources: BNEF and WNISR Original Research, 2023

Note: *In the absence of comprehensive, publicly available investment estimates for nuclear power by year, and to simplify the approach, WNISR includes the total projected investment costs in the year construction was started rather than spreading them out over the entire construction period. Furthermore, nuclear investment figures do not include revised budgets if—as generally is the case—cost overruns occur.

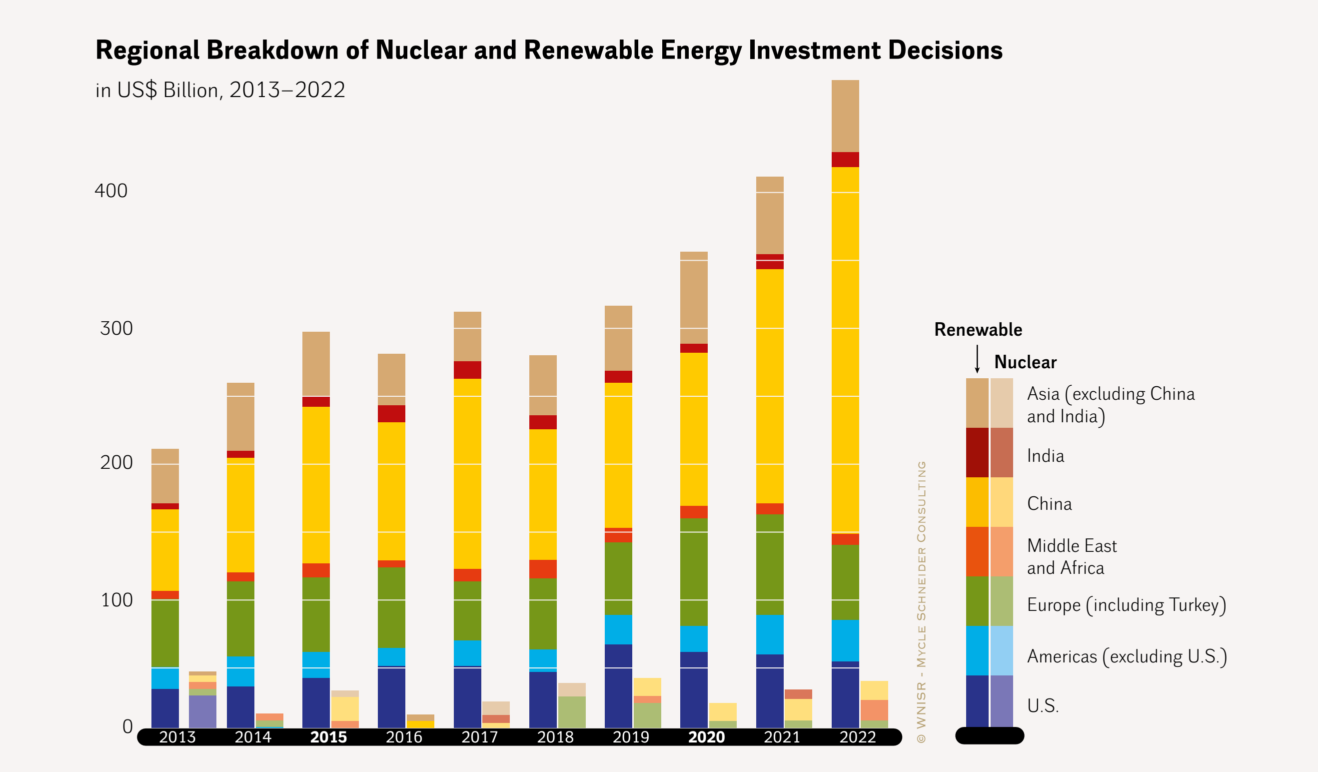
The International Energy Agency (IEA) has similar numbers and concluded that of the total 2022 investment in the power sector (around US$1.1 trillion), US$600 billion was for renewable energy (including hydro), about US$110 billion for fossil fuel plants and US$50 billion for nuclear, the remaining was allocated to the expansion and reinforcement of grids and storage.[1804]

Globally, China's global dominance in financial terms increased in 2022, as its investments towards renewables rose by over 55 percent to US$274.4 billion, primarily due to the growth in solar to US$164.5 billion with wind rising to US$109 billion. In 2022, investment in renewables in both the U.S. and Europe fell: by US$5.5 billion to US$49.5 billion in the U.S. and by US$20 billion to US$55.9 billion in Europe. In 2021, China's renewables investment was 35 percent larger than the combined European and U.S. investments. That gap increased to more than a factor of two in 2022. Furthermore, the investment in renewable energy in China in that year was larger, by some margin, than the total global investment in nuclear power over the past decade.[1805]

1804 - IEA, "World Energy Investment 2023 – Analysis", International Energy Agency, May 2023, see https://www.iea.org/reports/world-energy-investment-2023, accessed 25 May 2023.

1805 - REN21, "Renewables 2023 Global Status Report—Energy Supply", 2023, op. cit.

Figure 63 · Regional Breakdown of Nuclear and Renewable Energy Investment Decisions, 2013–2022



Sources: REN21, BNEF and WNISR Original Analysis, 2023

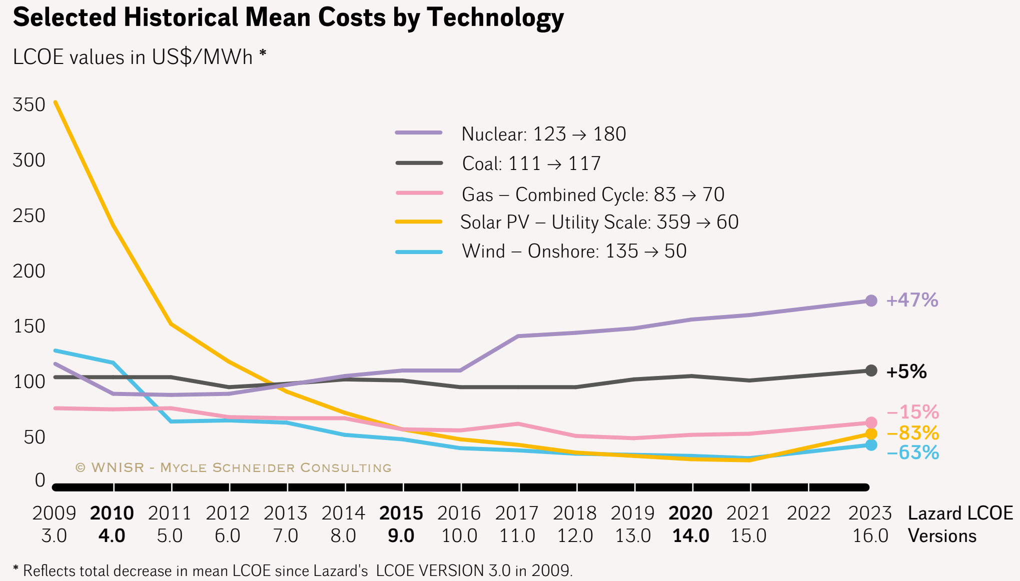
TECHNOLOGY COSTS

The annual comparative Levelized Cost of Energy (LCOE) analysis last updated in April 2023[1806] by Lazard, one of the oldest banks in the world—based on U.S. data but largely representative elsewhere—suggests that unsubsidized average electricity generating costs declined on average between 2009 and 2022 in the case of solar PV (crystalline, utility-scale) from US$359 to US$60 per MWh, a fall of 84 percent in spite of a 67-percent increase from the previous year. The cost-range has significantly widened to US$24–96/MWh. Wind power's LCOE dropped from US$135 to US$50 per MWh (a 63 percent fall) over the same period, while nuclear power costs went up from US$123 to US$180 per MWh, an increase of 46 percent (see Figure 64). Furthermore, Lazard has assessed that nuclear power is now the most expensive utility-scale power source for the first time, even more expensive than gas peaking plants.

The 2023 Lazard study included analysis on the costs associated with "firming" variable resources (e.g. adding storage), which vary hugely between different power markets across the U.S., but even including these costs, renewables remain below the cost of running gas peaking plants in all assessed markets and are in most cases—with the exception of the California market—in the lower range of the costs of running combined gas turbines for regular power generation.

1806 - Lazard, "Lazard's Levelized Cost of Energy Analysis—Version 16.0", 12 April 2023, see https://www.lazard.com/media/ruwg1jol/lazards-lcoeplus-april-2023.pdf, accessed 20 September 2023.

Figure 64 · The Declining Costs of Renewables vs. Traditional Power Sources



Source: Lazard Estimates, 2023

Notes: **LCOE**: Levelized Cost of Energy

*This graph reflects the average unsubsidized high and low LCOE range for a given version of LCOE study. It primarily relates to the North American renewable energy landscape but reflects broader/global cost declines.

Globally, the cost of renewables is now significantly below that of either nuclear power or natural gas. As with other sectors, inflation has affected the cost of producing renewable energy during 2022, as shown by Lazard and other analysts. However, BNEF, in their mid-2023 assessment revealed that the cheapest newbuild renewable energy projects in the first half of 2023 can be found in China, where an LCOE of US$23/MWh was achieved for the best-in-class onshore wind farms, US$50/MWh for offshore wind and US$31/MWh for fixed-axis PV farms.[1807]

In their annual review of renewable energy costs, the International Renewable Energy Agency (IRENA) concluded that in the single year 2022, the global weighted-average LCOE from new capacity additions of onshore wind declined by 5 percent to US$33/MWh and had fallen since 2010 by 69 percent. Over the same period, the LCOE of utility-scale photovoltaics was down 89 percent, to US$49/MWh.[1808]

IRENA calculated that 86 percent or 187 GW capacity of utility-scale renewables commissioned in 2022 produced cheaper electricity than the weighted average for fossil fuel generated power by country/region. Furthermore, they calculated that in 2022, the renewable power deployed in the world since 2000 saved the electricity sector an estimated US$521 billion in fuel costs.[1809]

1807 - BNEF, "Cost of Clean Energy Technologies Drop as Expensive Debt Offset by Cooling Commodity Prices", BloombergNEF, 7 June 2023, see https://about.bnef.com/blog/cost-of-clean-energy-technologies-drop-as-expensive-debt-offset-by-cooling-commodity-prices/, accessed 5 July 2023.

1808 - IRENA, "Renewable Power Generation Costs in 2022", International Renewable Energy Agency, August 2023, see https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022, accessed 13 October 2023.

1809 - Ibidem.

The IEA has calculated that E.U. electricity consumers are likely to save about €100 billion (~US$$_{2023}$110 billion) during the 2021–2023 period due to newly installed solar PV and wind capacity.[1810]

In Portugal, in 2022, the first "negative" power purchasing agreement was signed for a floating solar plant. In this historic case the operators would pay €4.13 (US$$_{2022}$4.35) for each megawatt hour generated over a 15-year period, the developers would make a profit because the project is a hybrid that also includes wind and energy storage. The solar panels are floating on the water of the pumped storage facility increasing their efficiency by cooling and reducing evaporation at the same time.[1811]

Running aging nuclear power plants generally leads to higher operating and maintenance costs. However, in the U.S. the nuclear industry has claimed a cost reduction of 38.9 percent since 2012 to US$29.13/MWh in 2021—the lowest since the collection of industry-wide data in 2002[1812] (see also Nuclear Economics and Finance). The analyses of potential implications on safety and security are not within the scope of this report. The U.S. nuclear operators have managed an impressive load factor of around 90 percent for most of the past two decades. That helps manage costs.

INSTALLED CAPACITY AND ELECTRICITY GENERATION

The continuing fall in the construction costs of renewables means there is an even more significant rise in the net annual increase in installed capacity when investment increases. A record 348 GW of new renewable energy capacity (including hydro) was installed in 2022, according to REN21, an increase of 13 percent over the addition in the previous year. However, to meet the IEA's net zero scenario targets, the rate needs to increase by about 2.5 times.[1813]

The pace of wind power deployment slowed slightly in 2022 with a net increase of 74.65 GW according to analysis from the International Renewable Energy Agency (IRENA), leading to 899 GW (in line with a total increase of 77 GW of global wind power capacity, including 68.4 GW onshore and nearly 8.8 GW offshore using REN21 figures).[1814] There was a relative slowdown in wind capacity deployment in most regions except for Europe. In the first half of 2023, the global wind sector passed a historic milestone with 1 TW of capacity being installed.

1810 - IEA, "Renewable Energy Market Update - June 2023 – Analysis", International Energy Agency, 1 June 2023, see https://www.iea.org/reports/renewable-energy-market-update-june-2023, accessed 1 June 2023.

1811 - Sergio Goncalves, "Portugal's floating solar energy auction sets world record negative price", *Reuters*, 5 April 2022, see https://www.reuters.com/business/sustainable-business/portugals-floating-solar-energy-auction-sets-world-record-negative-price-2022-04-05/, accessed 6 April 2022.

1812 - NEI, "Nuclear Costs in Context", Nuclear Energy Institute, October 2022, see https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/2022-Nuclear-Costs-in-Context.pdf, accessed 20 September 2023

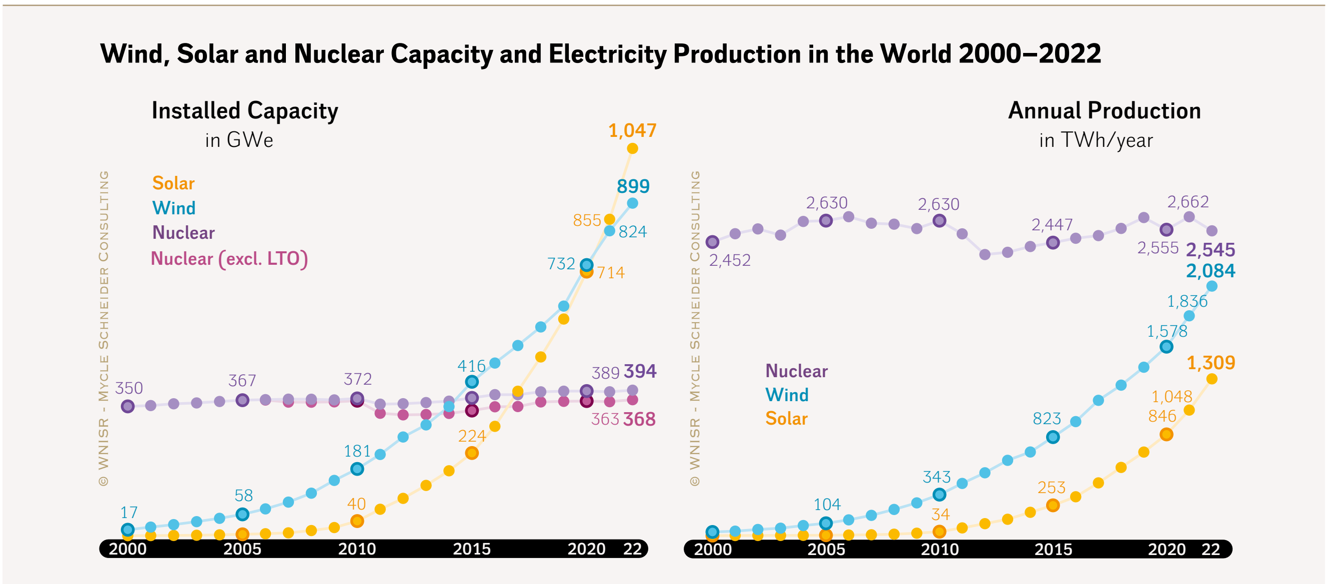
1813 - REN21, "Renewables 2023 Global Status Report—Energy Supply", 2023, op. cit.

1814 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf?rev=d2949151ee6a4625b65c82881403c2a7, accessed 20 September 2023.

The industry noted that it has taken more than 40 years to reach this, but it is envisaged to only take seven to achieve the next TW.[1815]

Solar PV deployment grew at an unprecedented rate, with an additional 191 GW according to IRENA and 243 GW according to REN21, being installed in 2022, an increase of 22–25 percent, taking the global total above 1 TW of installed capacity for the first time: 1,047 GW according to IRENA and 1,185 GW according to REN21.

Figure 65 • Wind, Solar and Nuclear Installed Capacity and Electricity Production in the World



Sources: WNISR with IAEA-PRIS, IRENA, Energy Institute, 2023

Note pertaining to Figure 65 to Figure 73 (except Figure 70):

Unless otherwise indicated, production data for renewables and nuclear are in net TWh from Energy Institute "Statistical Review of World Energy 2023 – Consolidated Dataset"; gross production numbers from Energy Institute are used for comparisons with fossil fuels (for which net data are not available).[1816]

Numbers for installed capacity for renewables are from IRENA[1817], and for nuclear capacity compiled by WNISR, based on IAEA-PRIS.

Figure 65 illustrates the extent to which renewables have been deployed since the start of the millennium, with an increase in capacity of 882 GW for wind and over 1 TW for solar, according to IRENA, compared to the relative stagnation of nuclear power capacity, which over this period increased by around 44 GW, including all reactors currently in Long-Term Outage (LTO). Considering that 25.7 GW of nuclear power was in LTO as of the end of 2022 and thus not generating any power, the balance is an addition of just about 18 GW operating capacity compared to 2000.

1815 - Demitra Alexandrou, "Wind Industry reaches 1 Terawatt Wind Energy Capacity Milestone", Press Release, Global Wind Energy Council, 15 June 2022, see https://gwec.net/1twcelebration/, accessed 7 August 2023.

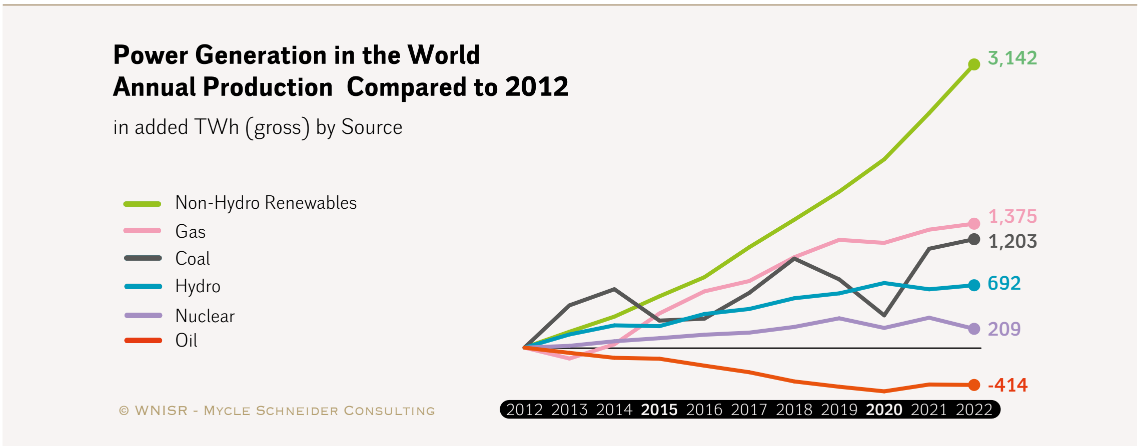
1816 - Energy Institute "Statistical Review of World Energy 2023 – Consolidated Dataset", see https://www.energyinst.org/statistical-review/resources-and-data-downloads; gross production numbers from Energy Institute are used for comparisons with fossil fuels (for which net data are not available).

1817 - IRENA, "Renewable Capacity Statistics", International Renewable Energy Agency, 2023, see https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf, accessed 23 March 2023.

The characteristics of electricity generating technologies vary due to different load factors. Over the year, operating nuclear power plants produce more electricity per installed MW than renewables. However, as can be seen in Figure 65, since the turn of the century, there has been an additional over 2,000 TWh of wind power and 1,300 TWh more solar power generated in 2022, compared to less than 100 TWh (net)[1818] of nuclear energy. In other words, over those 22 years, wind turbines added over 20 times more low-carbon electricity to the world's grids than nuclear power, while solar panels added 13 times more.

The growth of renewable energy is now not only outcompeting nuclear power but is rapidly overtaking fossil fuels and has become the source of economic choice for new generation. Figure 66 shows the extent to which, over the past decade, different energy sources have increased their electricity production. Non-hydro renewables have provided the greatest amount of additional electricity over the past decade, generating an additional 3,142 TWh (gross) of power. The next largest growth sectors were gas, coal, and hydro. Nuclear was the second smallest, with a net increase over the past decade of just 209 TWh, fifteen times less than the growth in non-hydro renewables.

Figure 66 · Added Electricity Generation by Power Source, 2012–2022



Source: Energy Institute, 2023

Note: see Figure 65.

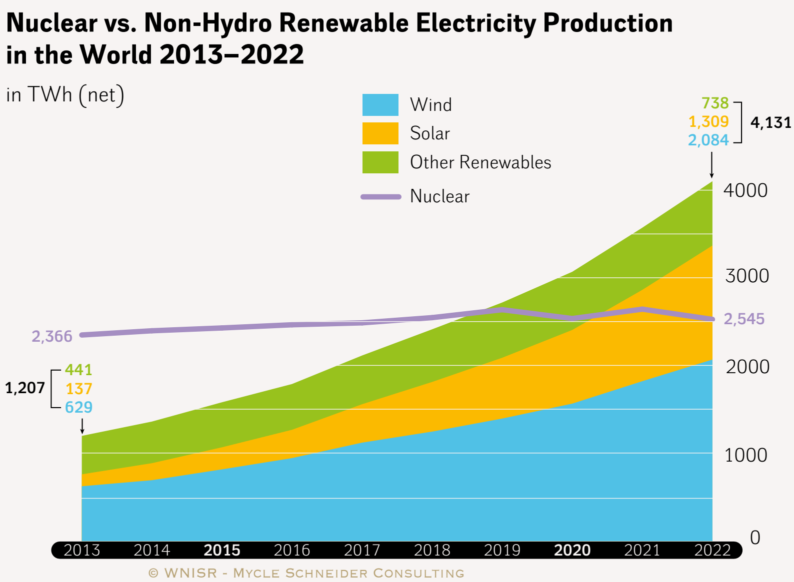
In 2019, for the first time, non-hydro renewables combined—solar, wind, and mainly biomass—generated more power than nuclear plants. In 2020, with the significant drop in nuclear output, the gap widened, and renewables generated 16.5 percent more electricity globally than nuclear reactors. In 2021, wind and solar alone reached a 10.2 percent share of power generation, "the first time wind and solar power have provided more than 10 percent of global power and surpassing the contribution of nuclear energy", as BP noted in its Statistical Review 2022.[1819] In 2022, solar and wind between them were more than 30 percent larger than nuclear.

1818 - Unless otherwise indicated, production data for renewables and nuclear are in net TWh from Energy Institute "Statistical Review of World Energy 2023 – Consolidated Dataset", see https://www.energyinst.org/statistical-review/resources-and-data-downloads; gross production numbers from Energy Institute are used for comparisons with fossil fuels (for which net data are not available).

1819 - BP, "Statistical Review of World Energy", 71st Edition, 2022, see https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf, accessed 21 September 2023.

Renewable energies' load factors have continued to improve. The annual load factor of a power plant describes the actual kWh compared to the theoretical production at full nominal capacity every hour of the year. Some power plants, in particular nuclear and coal fired stations, are described as baseload, as they are designed to operate as permanently as possible and not, or as little as possible, follow the demand load; this is traditionally done by gas fired power plants. On the other hand, solar and wind power plant are described as variable producers and have historically tended to have lower load factors, as their production is determined by climatic conditions.

Figure 67 · Nuclear vs. Non-Hydro Renewable Electricity Production in the World



Source: Energy Institute, 2023

Note: see Figure 65.

However, better engineering, operational management, and siting opportunities have increased the output and performance of renewables. In the case of wind power, between 2010 and 2020, global weighted average load factors rose by nearly a third to 36 percent for onshore wind, while driving down production costs. While the global load factor of newly commissioned utility-scale solar PV plants increased from 13.8 percent in 2010 to 16.1 percent in 2020.[1820]

Offshore wind opened up the opportunity for even greater improvements and in Europe, between 2010 and 2020, the average load factor for commissioned projects increased by 5 percentage points, from 39 percent to 44 percent. Even more remarkable has been the more recent success of Equinor's floating offshore of the coast of Scotland which has achieved an average load factor of 54 percent over its five years of operation.[1821] This is a higher load factor than the 52 percent achieved in 2022 for the French nuclear fleet.

1820 - IRENA, "Renewable Technology Innovation Indicators: Mapping progress in costs, patents and standards", International Renewable Energy Agency, March 2022, see https://www.irena.org/publications/2022/Mar/Renewable-Technology-Innovation-Indicators, accessed 9 August 2023.

1821 - equinor, "Equinor marks 5 years of operations at world's first floating wind farm", Press Release, 29 December 2022, see https://www.equinor.com/news/hywind-5-years-world-first-floating-wind-farm, accessed 21 September 2023.

The pace of deployment has not slowed in 2023, and according to the IEA, global renewable capacity additions are expected to exceed 440 GW, newly started up in 2023 alone, the largest absolute buildup ever. Executive Director of the IEA, Fatih Birol, said, "The global energy crisis has shown renewables are critical for making energy supplies not just cleaner but also more secure and affordable – and governments are responding with efforts to deploy them faster."[1822]

Analysis undertaken by the Rocky Mountain Institute, sums up the situation with renewables and other small modular technologies, such as batteries very clearly, stating that in previous evolutions of the energy sector the economics of the transition was linear, however, the current growth rates are exponential and will likely remain so, with annual growth rates of solar at 29 percent, wind 15 percent and batteries 54 percent.[1823$]

STATUS AND TRENDS IN CHINA, THE EUROPEAN UNION, INDIA, AND THE UNITED STATES

China

As noted earlier, China had a stellar year for solar PV deployment. By the end of 2022, China had deployed 44 percent of the world's new solar capacity of 392.4 GW. During the year, the installed capacity grew by 28 percent or 86 GW, according to IRENA. Analysis from REN21 suggests that the growth in 2022 was significantly larger, at 106 GW of which the vast rise in deployment was due to significant increases in distributed solar, with 61.4 GW being installed. The country's rooftop market was primarily driven by the three-year whole-county rooftop solar scheme, which launched in early 2021;[1824] a similar level of growth is expected in 2023.

Solar PV produced a total of 423 TWh of electricity in 2022, overtaking nuclear power for the first time that generated 397 TWh. In the first three months of 2023, China added another 33.66 GW of grid-connected solar power capacity, representing an increase of 155 percent year-on-year, data from the National Energy Administration (NEA) showed.[1825] According to the IEA, China is expected to remain the top renewable power implementer in 2023 and 2024 and to account for almost 55 percent of global capacity additions.[1826]

Wind power increased in China during 2022, but not at the pace of previous years with 32.6 GW onshore and more than 5 GW offshore, accounting for more than half of global additions.[1827] At the end of the year, there was 365.4 GW of wind, 334 GW onshore and 31.4 GW offshore. The slowdown in wind deployment is due to legislative changes and the phase-out of national feed-

1822 - IEA, "Renewable power on course to shatter more records as countries around the world speed up deployment", Press Release, International Energy Agency, 1 June 2023, see https://www.iea.org/news/renewable-power-on-course-to-shatter-more-records-as-countries-around-the-world-speed-up-deployment, accessed 21 September 2023.

1823 - Sam Butler-Sloss and Kingsmill Bond, "The Energy Transition in Five Charts and Not Too Many Numbers", Rocky Mountain Institute, 3 May 2023, see https://rmi.org/the-energy-transition-in-five-charts-and-not-too-many-numbers/, accessed 14 July 2023.

1824 - REN21, "Renewables 2023 Global Status Report—Energy Supply", 2023, op. cit.

1825 - Zheng Xin, "PV firms energized to add installed solar capacity", *China Daily*, 8 June 2023, see https://www.chinadaily.com.cn/a/202306/08/WS64810ecea31033ad3f7bb08d.html, accessed 21 September 2023.

1826 - IEA, "Renewable power on course to shatter more records as countries around the world speed up deployment", June 2023, op. cit.

1827 - REN21, "Renewables 2023 Global Status Report—Energy Supply", 2023, op. cit.

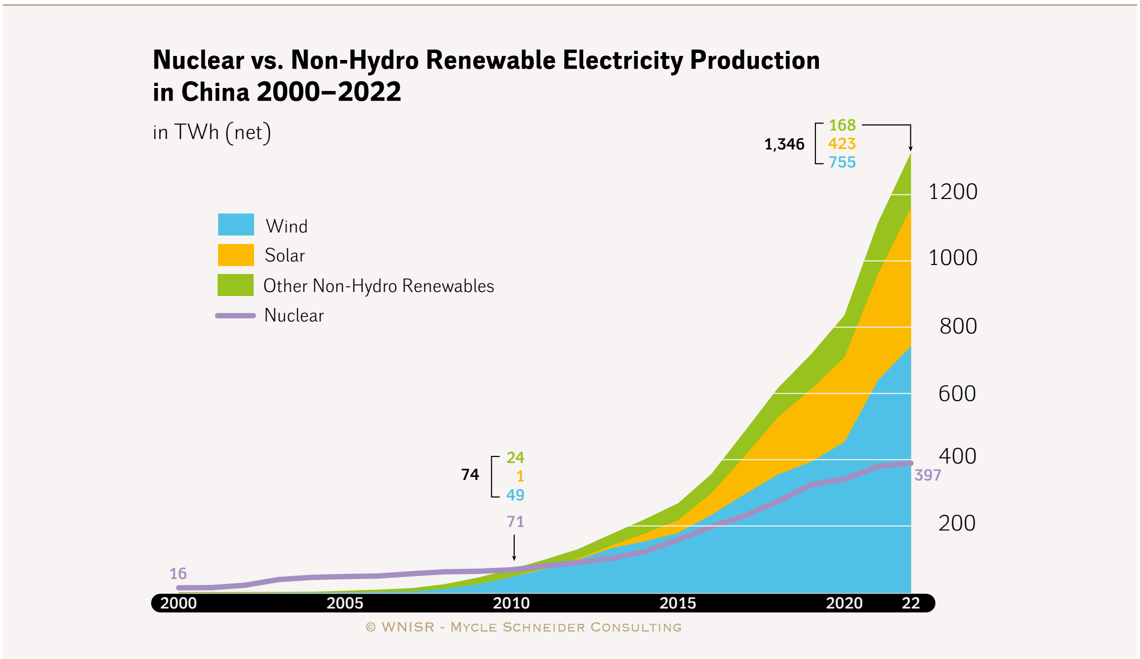
in tariffs for onshore wind, meaning that all new wind projects receive the same regulated price as coal projects in each province. In 2022 wind power produced 755.1 TWh, almost twice as much as nuclear power.

China also produces electricity from biomass, generating 157 TWh in 2022 – mainly from forest and agricultural biomass and municipal solid waste. While it is also a significant producer of energy from large scale hydropower, producing 1,290 TWh, accounting for 30 percent of the global total.[1828]

China produced 1,346 (net) TWh of non-hydro renewable energy in 2022, compared to 397 (net) of nuclear. That is more than twice the total power generation (577 TWh gross) of the world's third-largest economy, Germany.[1829]

Nuclear output grew 5.5 times between 2010 and 2022, while wind increased 15 times and solar over 600 times. As shown in Figure 68, based on data published by the Energy Institute (which differs slightly from that published by Chinese organizations), the total amount of energy generated by non-hydro renewables in 2022 is more than triple that of nuclear power. This growth is all the more remarkable as these technologies surpassed nuclear power only a little over a decade ago, and China is by far the world's leading nuclear power expanding country.

Figure 68 • Nuclear vs. Non-Hydro Renewables in China, 2000–2022



Source: Energy Institute, 2023

Note: see Figure 65.

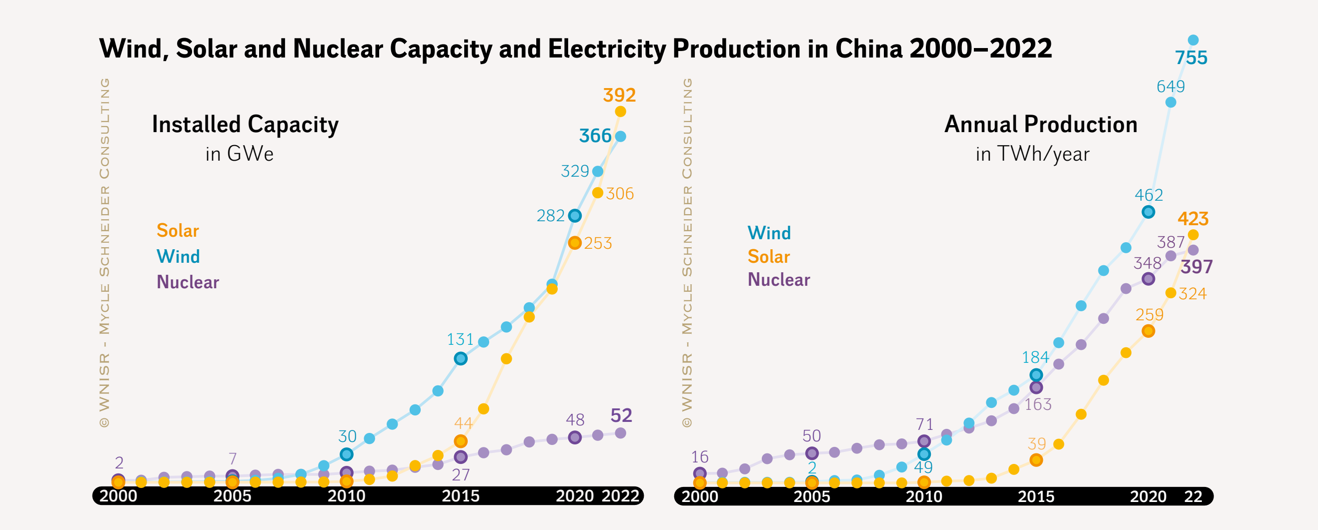
China's energy and climate policies are determined primarily by five-year plans and the National Energy Strategy (2016–2030), set initially nationally and then translated into provincial- and city-level targets. In March 2021, the Central Government announced its

1828 - Energy Institute "Statistical Review of World Energy", 72nd Edition, June 2023.

1829 - Ibidem.

intentions for the 14th Five-Year Plan (2021–2025), suggesting that the share of non-fossil fuels in the energy mix was to increase to 20 percent, up from 15 percent in the previous 5-year plan. Key high-level targets for the energy sector were also to improve the economy's energy intensity by 13.5 percent and carbon intensity by 18 percent over these five years.[1830]

Figure 69 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in China, 2000–2022



Sources: WNISR with IRENA, Energy Institute, IAEA-PRIS, 2023

According to the Energy Institute for 2022, non-fossil fuels accounted for 18.4 percent of the total primary energy consumption, with nuclear providing 2.4 percent, 7.7 percent from hydro and 8.3 percent from the rest of the renewables.

In June 2022, the National Development Reform Committee (NDRC) announced China's 14th FYP on renewables. This indicates a doubling of the use of renewables between the end of 2020 and 2025. However, an assessment of the current deployment projects of wind and solar capacity suggest that the target could be surpassed by 2025 as there would be a total installed capacity of 1,263 GW.[1831] A recent *Global Energy Monitor* report predicts that China will "shatter the central government's ambitious 2030 target of 1.2TW" and reach the goal already in 2025, five years ahead of schedule.[1832]

The 2030-targets for nuclear are less clear, some government researchers suggested it could be about 130 GW, a more than doubling of current capacity.[1833] Reaching such a target seems unlikely, given the long construction times of nuclear— over the past decade, 9.4 years on global average and in China an average of six years—with only 22.9 GW under construction

1830 - Michal Meidan, Philip Andrews-Speed, and Yan Qin, "Key issues for China's 14th Five Year Plan", Oxford Insitute for Energy Studies, and University of Singapore, March 2021, see https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/03/Key-issues-for-Chinas-14th-Five-Year-Plan.pdf, accessed 13 October 2023.

1831 - Bing Han, "China's renewables 14th Five-Year Plan: Official targets to be remarkably outpaced?", S&P Global, 20 July 2022, see https://www.spglobal.com/commodityinsights/en/ci/research-analysis/chinas-renewables-14th-fiveyear-plan-official-targets.html, accessed 13 October 2023.

1832 - Florence Jones, "China to 'shatter' renewable installation targets by 2030", *Power Technology*, 29 June 2023, see https://www.power-technology.com/news/china-shatter-renewable-installation-target/, accessed 9 October 2023.

1833 - Jason Rogers, "China to miss nuclear energy target this year, but has eyes set on dominating sector by 2030", *ThePrint*, 2 June 2020, see https://theprint.in/world/china-to-miss-nuclear-energy-target-this-year-but-has-eyes-set-on-dominating-sector-by-2030/433899/, accessed 5 July 2023.

as of the end of 2022, of which around 9 GW expected to come online by the end of 2025. Therefore, at best, China will have 61 GW of nuclear capacity operating by the end of the 14th Five-Year Plan. As reported in earlier WNISR-editions, the country missed its Five-Year Plan 2020-target and will miss its 2025 target.

The total capacity operating and under construction as of 1 July 2023 represents around 77.5 GW. In its Nuclear Energy Development Report of 2023, the China Nuclear Energy Industry Association suggests that by 2035 the share of nuclear in the electricity mix could double from 2022 levels and thus reach around 10 percent.[1834] However, nuclear power would still remain an order of magnitude below the installed capacity and significantly below the output of each, solar and wind, individually.

European Union

According to the Non-Governmental Organization Ember, electricity demand in the European Union (E.U.) in 2022 was 2,809 TWh – or about ten percent of the global total.[1835] E.U. demand fell by 2.7 percent (79 TWh) from 2,888 TWh in 2021. The fall in demand was primarily due to mild winter weather, alongside demand reduction, driven partly by high electricity prices.

In 2022, renewable electricity generation in the E.U. reached a new record of 1,080 TWh. This was mainly due to a significant rise in solar electricity, providing 203 TWh or 7.3 percent of the total, up 24 percent from the previous year. In 2000, solar in Member States provided just 0.1 TWh. Wind power production increased by 8.6 percent to 420 TWh or 15 percent of the total in 2022.[1836]

Low rainfalls meant that power from hydro fell to a level never previously encountered in the 21st century, producing just 281 TWh. According to the IEA, newly installed solar PV and wind capacity are estimated to have saved E.U. electricity consumers €100 billion (~US$$_{2023}$110 billion) during 2021–2023 by displacing more expensive fossil fuel generation. Wholesale electricity prices in Europe would have been 8 percent higher in 2022 without the *additional* renewable capacity.[1837] Key highlights for renewables in the E.U. include:

- In **Denmark**, 60 percent of power came from renewables in 2022, up from 47 percent in 2021.[1838]
- In **Germany**, in the 1st half of 2023, renewables produced 52 percent of power.[1839]

1834 - ce.cn, "2030年前我国在运核电装机规模有望成世界第一" ["China's installed nuclear power capacity in operation by 2030 is expected to become the world's largest"], 27 April 2023, see http://www.ce.cn/cysc/ny/gdxw/202304/27/t20230427_38522104.shtml, accessed 9 August 2023.

1835 - EMBER, "European Electricity Review 2023", 2023, see https://ember-climate.org/app/uploads/2023/01/Report-European-Electricity-Review-2023.pdf, accessed 22 September 2023.

1836 - EMBER, "European Electricity Review 2023", 2023.

1837 - IEA, "Renewable power on course to shatter more records as countries around the world speed up deployment", June 2023, op. cit.

1838 - Jesper Berggreen, "Another Year, Another Record In Denmark's Renewable Energy Progress", *CleanTechnica*, 14 January 2023, see https://cleantechnica.com/2023/01/14/another-year-another-record-in-denmarks-renewable-energy-progress/, accessed 22 September 2023.

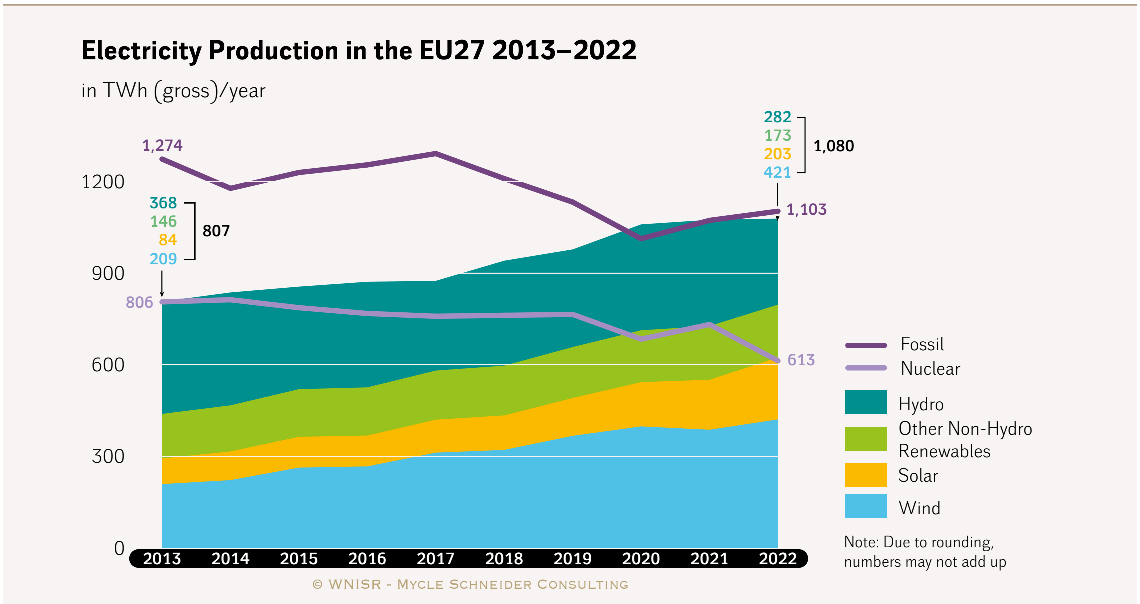
1839 - Bernd Radowitz, "Renewables meet record 52% of German power needs but 'expansion must take place faster'", *Recharge*, 28 June 2023, see https://www.rechargenews.com/energy-transition/renewables-meet-record-52-of-german-power-needs-but-expansion-must-take-place-faster/2-1-1476200, accessed 22 September 2023.

- In **Portugal**, in January 2023, renewables provided 88 percent of electricity, and during the whole year of 2022 an average of 60 percent.[1840]
- In **Spain**, in May 2023, over a nine-hour period of a working day, the whole of the country's power demand was met by renewables.[1841]

In Germany, auctions were held for 7 GW of offshore wind in July 2023, the biggest auction to date, across a number of sites. In each case more than one company bid to build the wind fields, without any subsidy, which triggered a 2nd round of 'uncapped negative bidding'. This resulted in the developers having to eventually pay a total of €12.6 billion (US$13.7 billion) to the German Government, with 90 percent of the revenues funding the grid connection costs, 5 percent maritime biodiversity, another 5 percent environmentally-friendly fishing.[1842]

Nuclear power also had a poor production year, with just 613 TWh being produced or 21.9 percent of the total, that is a drop by 119 TWh or 16 percent compared to 2021 (see Figure 70).[1843] Ten years ago, nuclear accounted for 29 percent of the E.U.'s power generation. The decline in nuclear electricity was primarily due to an 82 TWh decline from the French reactors, due to technical problems, extended outages for decennial inspection and repairs, lack of cooling water, and strikes (see France Focus for details).

Figure 70 · Electricity Generation in the EU27 by Fuel, 2013–2022



Source: Ember, 2023

1840 - Sergio Goncalves, "Renewables supplied 88% of Portugal's electricity consumption in January", *Reuters*, 1 February 2023, see https://www.reuters.com/world/americas/renewables-supplied-88-portugals-electricity-consumption-january-2023-02-01/, accessed 9 July 2023.

1841 - Ignacio Fariza, "The nine hours in which Spain made the 100% renewable dream a reality", *EL PAÍS English*, 19 May 2023, see https://english.elpais.com/spain/2023-05-19/the-nine-hours-in-which-spain-made-the-100-renewable-dream-a-reality.html, accessed 20 May 2023.

1842 - WindEurope, "German offshore auctions award 7 GW of new wind; future auctions must avoid negative bidding", Press Release, 12 July 2023, see https://windeurope.org/newsroom/press-releases/german-offshore-auctions-award-7-gw-of-new-wind-future-auctions-must-avoid-negative-bidding/, accessed 13 July 2023.

1843 - EMBER, "European Electricity Review 2023", 2023, op. cit.

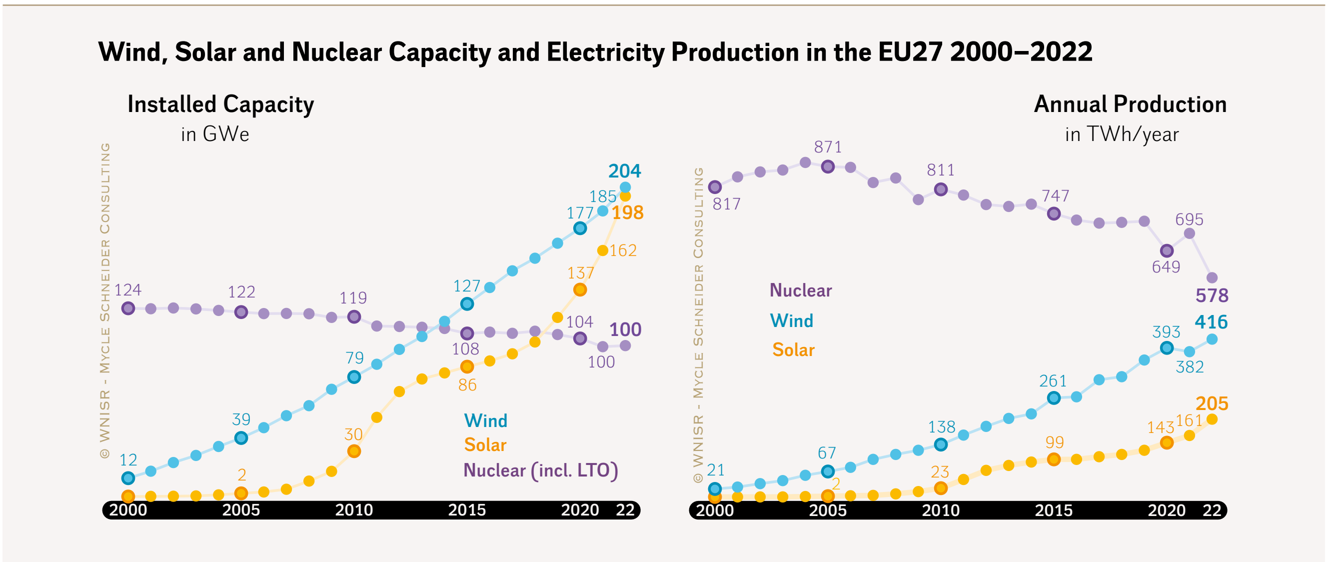
"For the first time ever, solar and wind generated more electricity in the E.U. than nuclear and natural gas."

Solar and wind generated a total of 624 TWh and thus, for the first time ever, exceeded nuclear and natural gas output while remaining above coal.

In 2022, natural gas accounted for 20 percent of the total electricity generation, marginally up (by 0.7 percent from the previous year), coal 16 percent, and other fossil fuels 3.6 percent.[1844]

Since 2000, wind added 192 GW of installed capacity, solar 198 GW, while nuclear declined by 23.3 GW. Since the signature of the Kyoto Protocol in 1997, wind and solar increased annual production by 410 TWh and 205 TWh respectively, while nuclear generated 219 TWh less power (see Figure 71).

Figure 71 · Wind, Solar and Nuclear Capacity and Electricity Production in the EU27



Sources: WNISR with IAEA-PRIS, Energy Institute, IRENA, 2023

Note: see Figure 65.

Energy policy in the E.U. has had to respond to significant external and internal forces over the past few years. Firstly, in September 2020, the European Commission proposed to increase the E.U.'s GHG reduction target to at least 55 percent by 2030 from 1990 levels, up from the 40 percent minimum target set before the signing of the Paris Agreement in 2015. The European Commission's background paper for the revised targets states that "the scenarios achieving 55 percent GHG ambition (including intra E.U. aviation and navigation emissions in the target scope) arrive at the RES [Renewable Energy Sources] share of between 37.5 percent to 39 percent (…)"[1845] There is no E.U.-wide nuclear deployment target.

Then in response to the war in Ukraine and in line with the E.U.'s objective to rapidly reduce its dependency on Russian energy, the European Commission published a new energy plan called

1844 - Ibidem.

1845 - European Commission, "Commission Staff Working Document—Impact Assessment—Stepping up Europe's 2030 climate ambition", 17 September 2020, see https://eur-lex.europa.eu/resource.html?uri=cellar:749e04bb-f8c5-11ea-991b-01aa75ed71a1.0001.02/DOC_1&format=PDF, accessed 22 September 2023.

the REPowerEU plan. This introduced several supply and demand side measures to reduce dependency on Russia and address climate change simultaneously. As the name suggests, a cornerstone of the new plan was an increase in renewable energy, with an ambition to provide 45 percent (up from 40 percent) of the E.U.'s final energy by 2030, about double its current contribution.[1846]

This included a specific solar strategy to more than double the current capacity by 2025 (solar PV is currently about 150 GW) and to have close to 600 GW installed by 2030. Legal obligations on rooftop solar in new public and commercial buildings and the residential sector, as well as changes in planning and new targets on the production of green hydrogen.

In contrast, on nuclear power, the European Commission Communication says this: "In parallel, some of the existing coal capacities might also be used longer than initially expected, with a role for nuclear power and domestic gas resources too." Therefore, there are no targets, no additional support, only a brief reference to its current role and a desire to reduce dependency on uranium imports from Russia.[1847]

In response to the U.S. Inflation Reduction Act (IRA), the European Commission has set out its own "Green Deal Industrial Plan", proposing, among other things, a significant relaxation of the E.U.'s state aid rules regarding investment in green technology. It is suggested that the E.U. will clear the way—through state aid reforms—to allow E.U. Member States to "match" multi-billion-euro incentives as they fight to keep projects in Europe.[1848]

The European Commission has also proposed a Net-Zero Industry Act (NZIA), which will require domestic sources and technology production to meet energy security and climate change targets. Along with NZIA, the European Commission published the Critical Raw Materials Act to ensure adequate raw materials and new legislation on the energy market reform.[1849] The NZIA supports strategic technologies that are available soon to enter the market, including solar, wind, electrolysers, batteries, and storage. The Act supports other technologies, including "advanced technologies to produce energy from nuclear processes with minimal waste from the fuel cycle, small modular reactors, and related best-in-class fuels."[1850] The nuclear industry was said to be frustrated by the Commission's categorization and nuclear not being included as a 'strategic' industry, denouncing it as "incoherent".[1851]

1846 - European Commission, "REPowerEU Plan", Communication to the European Parliament, the European Council, the Council, The European Economic and Social Committee and the Committee of the Regions, 18 May 2022, see https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0230, accessed 22 September 2023.

1847 - Ibidem.

1848 - European Commission, "The Green Deal Industrial Plan: putting Europe's net-zero industry in the lead", Press Release, 1 February 2023, see https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510; and Policy Department for Economic, Scientific and Quality of Life Policies, "EU's response to the US Inflation Reduction Act (IRA)", Briefing commissioned by the Committee on Economic and Monetary Affairs, European Parliament, June 2023, see https://www.europarl.europa.eu/RegData/etudes/IDAN/2023/740087/IPOL_IDA(2023)740087_EN.pdf; both accessed 22 September 2023.

1849 - European Commission, "The Net-Zero Industry Act: Accelerating the transition to climate neutrality", 16 March 2023, see https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en, accessed 22 September 2023.

1850 - European Commission, "Questions and Answers: The Net-Zero Industry Act and European Hydrogen Bank", 16 March2023, see https://ec.europa.eu/commission/presscorner/detail/en/QANDA_23_1666, accessed 22 September 2023.

1851 - Frédéric Simon, "'Not there yet': France's EDF frustrated with nuclear power's status in EU's Net-Zero Industry Act", *Euractiv*, 11 June 2023, see https://www.euractiv.com/section/energy-environment/news/not-there-yet-frances-edf-frustrated-with-nuclear-powers-status-in-eus-net-zero-industry-act/, accessed 22 September 2023.

In March 2023, agreement was finally reached between the E.U. institutions so that a binding target for renewable energy of 42.5 percent (with an additional 2.5 percent voluntary target) by 2030 was adopted. Sector targets were set for transport (14.5 percent greenhouse gas intensity reduction or 29 percent share of renewable energy in final energy consumption), a specific renewable energy benchmark of 49 percent for energy consumption in buildings by 2030 and a binding target to reach 42 percent of renewable hydrogen in total hydrogen consumption in industry by 2030.[1852] There is no binding target for the power sector, but meeting the overall target will probably mean a power sector supplied by around 70 percent from renewables. Given the variability of renewable energy production, there will be substantial parts of any day that renewables will provide all the power leading to additional problems for generators, like nuclear, which are less flexible and have limited load following-capabilities. Also, any kWh lost to renewables will cut further into nuclear's difficult economic situation in the market.

India

Since 2010, the installed solar capacity in India has increased from 70 MW to 62.8 GW at the end of 2022, a nearly 1000-fold increase. During the year, 13 GW of utility scale were added, more than any other year, and the third largest increase globally behind China and the U.S. The capacity of wind power increased to a total of 41.9 GW by the end of the year.[1853] However, for 2023 the IEA suggests that "lower auction volumes and supply-chain challenges indicate that a slowdown of almost 20 percent is probable" on the short term.[1854]

Despite the recent gains, India has failed by large margins to meet its 2016-targets for deploying renewables with 175 GW by the end of 2022, including 100 GW solar and 60 GW wind. Consequently, the government is seeking to inject more pace into the sector and announced in April 2023 that 50 GW of solar and wind will be auctioned annually up until 2028.[1855]

Figure 72 shows that since the turn of the century, wind power output has grown almost 45-fold, from 1.6 TWh to 69.3 TWh in 2022 and has overtaken nuclear's annual contribution to electricity generation since 2016, which now stands at 44 TWh. Solar is growing even faster, from virtual inexistence with a production of 7 GWh in 2000 to 94.2 TWh in 2022—representing a sky-rocketing expansion by a factor of nearly 10,000 in two decades. In 2021, solar also (just) outpaced wind in power generation for the first time.[1856] In 2022, according to Energy Institute data, fossil fuels still accounted for about 77 percent of the country's electricity generation, with coal contributing 74.3 percent, natural gas 2.5 percent and oil about 0.1 percent.

The gap in output between renewables and nuclear will likely increase in the coming years because of the rapid growth of solar and wind capacity and the low growth in the nuclear sector over the past few years.

1852 - European Commission, "European Green Deal: EU agrees stronger legislation to accelerate the rollout of renewable energy", Press Release, 30 March 2023, see https://ec.europa.eu/commission/presscorner/detail/en/IP_23_2061, accessed 22 September 2023.

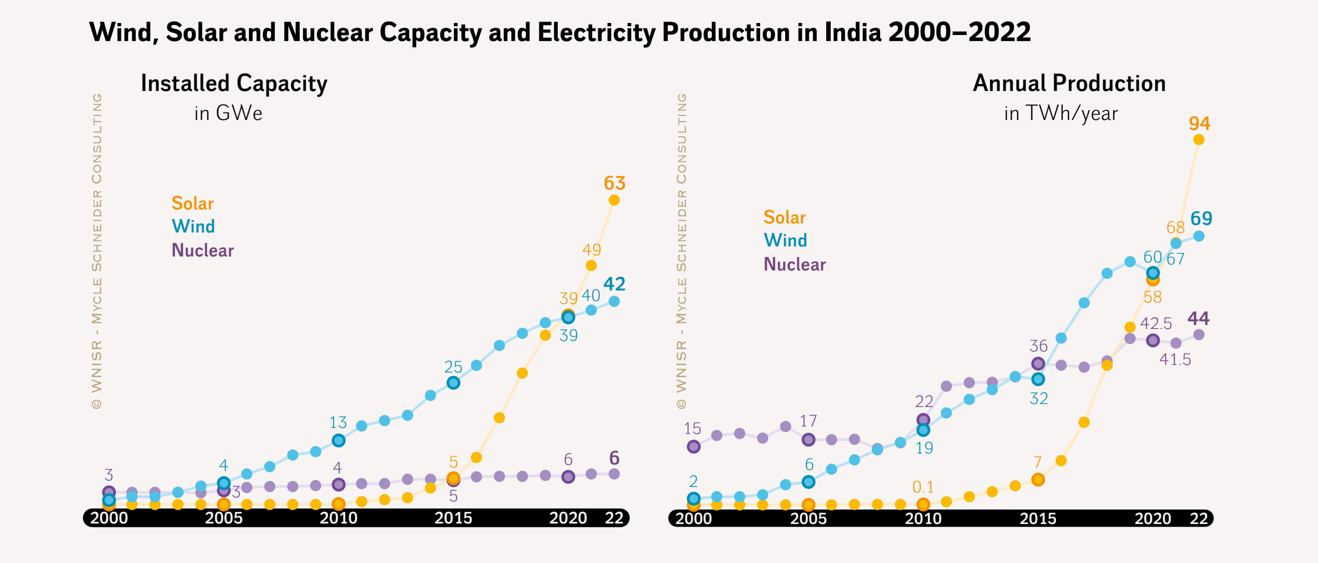
1853 - IRENA, "Renewable Capacity Statistics", 2023, op. cit.

1854 - IEA, "Renewable Energy Market Update", June 2023, op. cit.

1855 - Benjamin Parkin, "India's renewables industry under pressure to fulfil government's target", *Financial Times*, 8 April 2023, see https://www.ft.com/content/699cb5a7-9a65-4c1a-9ab7-919d652ae9d1, accessed 9 August 2023.

1856 - Energy Institute, "Statistical Review of World Energy", June 2023, op. cit.

Figure 72 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in India



Sources: WNISR with IAEA-PRIS, IRENA, Energy Institute, 2023

Note: see Figure 65.

United States

As of mid-2023, the U.S. had 93 operating commercial nuclear reactors, down from 101 in 2012. In 2019, the industry succeeded in generating a new record volume of electricity, with 809 TWh supplying just under 20 percent of the nation's electricity, but by 2022 that had fallen by 4.7 percent to 772 TWh or 18.2 percent of the total.

"The combined output from all renewables was more than coal for the first time"

In contrast, the U.S. generated a record amount of renewable energy in 2022, with the combined output from solar and wind rising from 12 percent in 2021 to 14 percent in 2022. The installed capacity of utility-scale solar increased by 10 GW to 71 GW, while wind increased by 8 GW to 141 GW.[1857] The combined output from all renewables, solar and wind, plus geothermal, biomass and hydro, was more than coal for the first time, with natural gas now the only more significant generator. According to the U.S. Energy Information Agency, in 2023, 82 percent of new capacity is expected to be wind, solar and battery storage,[1858] with half of the total expected to be solar (29 GW) and 2.2 GW to be nuclear (the two Vogtle reactors in Georgia, one of which started up in April 2023, see United States Focus).

The pace of transformation could and needs to go much faster and an assessment by Berkeley Labs suggested that there are about 2,000 GW of solar, storage, and wind waiting to be

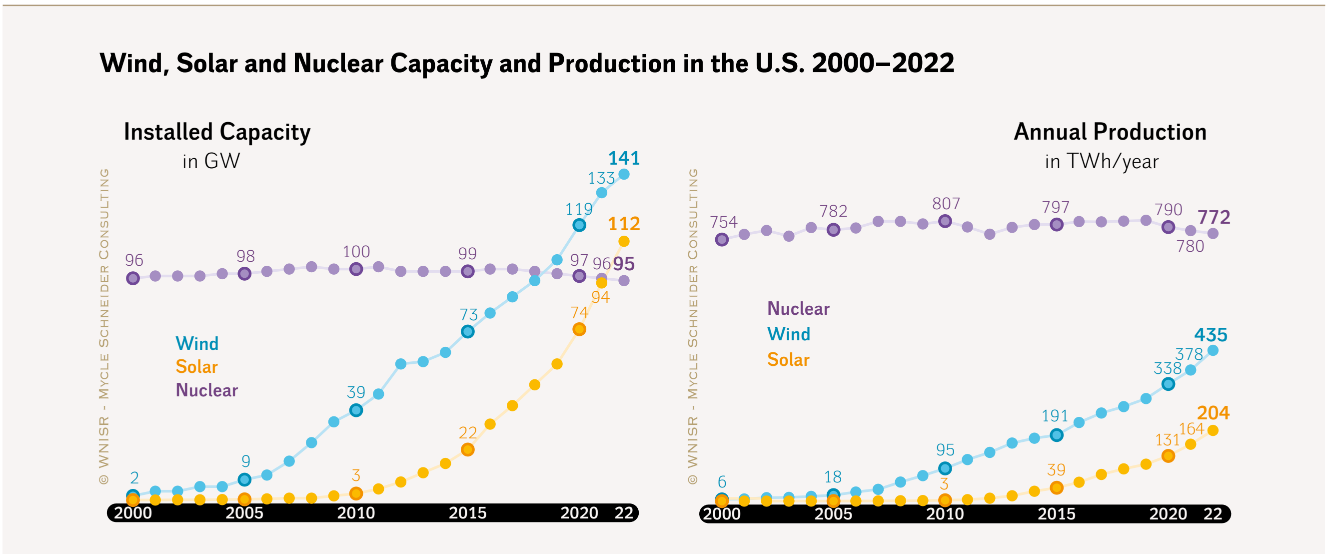
1857 - U.S.EIA, "Today in Energy—Renewable generation surpassed coal and nuclear in the U.S. electric power sector in 2022", U.S. Energy Information Administration, 27 March 2023, see https://www.eia.gov/todayinenergy/detail.php?id=55960, accessed 5 July 2023.

1858 - U.S. EIA, "Today in Energy—Wind, solar, and batteries increasingly account for more new U.S. power capacity additions", U.S. Energy Information Administration, 6 March 2023, see https://www.eia.gov/todayinenergy/detail.php?id=55719, accessed 5 July 2023.

connected nation-wide—this is double the current capacity of the U.S. grid.[1859] In July the Federal Regulator changed the regulatory process to speed up the licensing of renewables. The package of reforms included impositions of firm deadlines and fines for transmission providers for failing to meet agreed deadlines.[1860]

The election of President Biden in 2020 led to a significant change in direction on several issues, particularly climate change, including rejoining the Paris Agreement and a pledge to submit a revised NDC. The administration delivered on its promise at the U.S.-convened Climate Leaders' Summit in April 2021 and committed to a 50–52 percent reduction from 2005 levels by 2030 in its new NDC.[1861] In a Presidential plan to 'Re-energize' America's power infrastructure, the White House pledged to put the U.S. "on the path to achieving 100 percent carbon-free electricity by 2035".[1862]

Figure 73 • Wind, Solar and Nuclear Installed Capacity and Electricity Production in the United States



Sources: WNISR with Energy Institute, IRENA, and IAEA-PRIS, 2023

Note: see Figure 65.

In August 2022, the Inflation Reduction Act (IRA) was adopted, and it provided for US$500 billion in new spending and tax breaks that aim to boost clean energy, reduce healthcare costs, and increase tax revenues.[1863] This is the third piece of legislation passed since late 2021 to improve U.S. economic competitiveness, innovation, and industrial productivity.

1859 - Electricty Markets and Policy Group, "Grid connection requests grow by 40% in 2022 as clean energy surges, despite backlogs and uncertainty", Berkley Lab, Lawrence Berkeley National Laboratory, University of California, U.S. Department of Energy, 6 April 2023, see https://emp.lbl.gov/news/grid-connection-requests-grow-40-2022-clean, accessed 9 August 2023.

1860 - FERC, "Transmission Reform Paves Way for Adding New Energy Resources to Grid", Press Release, Federal Energy Regulatory Commission, 27 July 2023, see https://www.ferc.gov/news-events/news/ferc-transmission-reform-paves-way-adding-new-energy-resources-grid, accessed 13 October 2023.

1861 - U.S. State Department, "Leaders Climate on Climate: Day 1", United States Department of State, 22 April 2021, see https://www.state.gov/leaders-summit-on-climate/day-1/, accessed 22 September 2023.

1862 - The White House, "FACT SHEET: The American Jobs Plan", United States Government, 31 March 2021, see https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/, accessed 5 July 2023.

1863 - U.S. Government, Public Law 117–169, 16 August 2022, see https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf, accessed 22 September 2023.

The Bipartisan Infrastructure Law (BIL), the CHIPS [Creating Helpful Incentives to Produce Semiconductors] & Science Act, and IRA have partially overlapped priorities and introduce US$2 trillion in new federal spending over the next ten years.

The IRA directs nearly US$400 billion in federal funding to clean energy to substantially lower the nation's carbon emissions by the end of this decade. The funds will be delivered through a mix of tax incentives, grants, and loan guarantees. Clean electricity and transmission command the most significant slice, followed by clean transportation, including electric vehicle (E.V.) incentives. Nuclear power is also the recipient of changes in funding, and in addition to providing new production tax credits for existing nuclear plants, the IRA also delivers numerous technology-neutral credits aimed at low- or zero-carbon energy sources, including nuclear (see United States Focus).[1864]

CONCLUSION ON NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

The challenge for energy policy has always been to secure the triple societal objectives of sustainability, security, and affordability—the so-called energy trilemma. While stable policies are beneficial as they help secure investment, policies and measures must be responsive to external events and changing understanding, including science. Climate change in many parts of the world was a priority during 2021, mainly due to the publication of the final parts of the 6th Assessment Report of the International Panel on Climate Change and the occasion of COP26 of the UNFCCC. However, Russia's full-scale invasion of Ukraine in February 2022 has re-prioritized energy supply security and put into stark focus the impacts of higher energy prices.

There is no doubt that the situation is extremely serious, Russia is also a significant exporter of energy, and we will likely continue to see high price levels and the subsequent cost of living crisis across the world.

On the supply side, 2021 and 2022 have once again shown that renewable energy outperforms nuclear power in terms of cost, and as is documented throughout this report, nuclear power is slow to build. Therefore, although there has been increased attention to nuclear power recently, the deployment of renewable energy, as graphically demonstrated in the E.U., is being promoted as the key supply option. Antonio Guterres, the United Nations Secretary-General stated: "We are still addicted to fossil fuels: The only true path to energy security, stable power prices, prosperity & a livable planet lies in quitting fossil fuels & accelerating the transition to renewables."[1865]

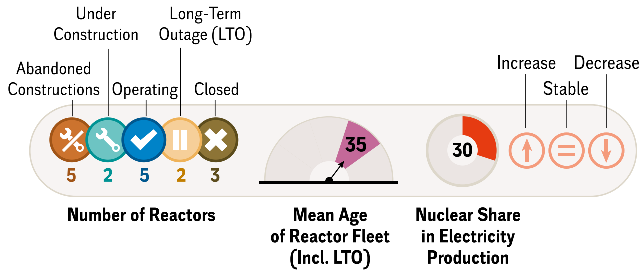
1864 - Ryan Lighty and Kirstin Gibbs, "A new era for nuclear energy post Inflation Reduction Act", *Reuters*, 21 December 2022, see https://www.reuters.com/legal/legalindustry/new-era-nuclear-energy-post-inflation-reduction-act-2022-12-21/, accessed 5 July 2023.

1865 - António Guterres, Twitter, 9 July 2022, see https://twitter.com/antonioguterres/status/1545725702472966145, accessed 22 September 2023.

TABLE OF ANNEXES

ANNEX 1 – OVERVIEW BY REGION AND COUNTRY

These "quick view" indicators will be used in the country sections throughout the report.



Unless otherwise noted, data on reactor capacity (as of mid-2023) and nuclear's share in electricity generation in 2022 are from the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS) online database.

Numbers of reactors under construction, operating, in LTO or closed are WNISR assessments based on IAEA-PRIS and industry data. Historical maximum figures indicate the year that the nuclear share in power generation of a given country was the highest since 1986, the year the Chernobyl disaster began.

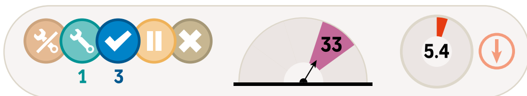
AFRICA

South Africa

See Focus Countries – South Africa Focus.

THE AMERICAS

Argentina



Argentina operates three nuclear reactors that provided 7.47 TWh in 2022 (26.5 percent less than in 2021), which represented 5.4 percent of the country's electricity generation (compared to 7.2 percent the previous year, and a maximum of 19.8 percent in 1990).[1866] The three units were all supplied by foreign reactor builders. Atucha-1 and -2 were built by the German company Siemens, and the CANDU (CANadian Deuterium Uranium) reactor at Embalse by Canadian Atomic Energy of Canada Limited (AECL).

In April 2018, the regulatory authority granted a lifetime-extension license to enable Atucha-1, which started up in 1974, to continue operating until 2024, allowing a 50-year working

1866 - Based on IAEA-PRIS. According to governmental data, nuclear generated 7.5 TWh and contributed 5.7 percent in 2022; see Energy Information Directorate, "Relevamiento Estadístico de Energía Sector Eléctrico – Año 2022", Subsecretariat of Energy Planning, State Secretariat for Energy, Ministry of Economy, Government of Argentina, September 2023, see http://datos.energia.gob.ar/dataset/anuarios-de-energia-electrica, accessed 30 October 2023.

lifetime.[1867] In early July 2022, it was announced that the owner and operator, Nucleoeléctrica Argentina SA (NA-SA) and the regulator had signed a framework agreement for an additional 20 years of operation.

The lifetime extension entails an expansion of spent fuel storage capacity onsite, and refurbishment work to be carried out once the reactor is taken offline upon expiration of its current license. A dry storage facility (ASECG I) at Atucha-1 was commissioned in late August 2022 requiring an estimated investment of ARS6,000 million (~US$$_{2022}$46 million).[1868] Refurbishment is expected to take 30 months and cost US$463 million, while the construction of a second dry storage facility at Atucha-1 (ASECG II) is to cost about US$137 million. Both projects are planned to be completed by 2026.[1869]

Atucha-2 was ordered in 1979, and construction was stop/start over the following decades, but finally, grid connection occurred on 27 June 2014, but took until 26 May 2016 to enter commercial operation.[1870] Performance has been mediocre in the past four years. Although the unit's annual load factor had been on a slow rise between 2019 and 2021 (from 29 percent to 49 percent and finally 58 percent), according to IAEA-PRIS, it fell to just under 21 percent in 2022, the lowest of its operational history.[1871] The latest poor performance is mainly due to two outages which kept the unit offline for over 220 days that year.

First, an outage scheduled to carry out various maintenance and inspections tasks, mandatory for the issuance of a license renewal in 2023, took place from 9 March to 26 July 2022.[1872] Then, in early October 2022, an unscheduled shutdown turned into an outage that was still ongoing as of mid-2023. The shutdown was prompted by the detection of excessive vibrations in the reactor's turbine.[1873, 1874]

1867 - *WNN*, "Atucha-1 operating licence renewed", *World Nuclear News*, 16 April 2018, see http://www.world-nuclear-news.org/RS-Atucha-1-operating-licence-renewed-1604184.html, accessed 7 May 2021; and Nucleoeléctrica Argentina, "Atucha I extendió su Licencia de Operación hasta 2024", Press Release, 12 April 2018.

1868 - NA-SA, "Nucleoeléctrica finalizó la construcción del almacenamiento en seco de elementos combustibles en Atucha, una obra de ingeniería fundamental para la operación de la Central", Press Release (in Spanish), Nucleoeléctrica Argentina S.A., 29 August 2022, see https://www.na-sa.com.ar/es/prensa/nucleoelectrica-finalizo-la-construccion-del-almacenamiento-en-seco-de-elementos-combustibles-en-atucha-una-obra-de-ingenieria-fundamental-para-la-operacion-de-la-central-319, accessed 1 November 2023.

1869 - Ministry of Economy, "Fideicomiso para Atucha I en la agenda que impulsa la CNV", Press Release (in Spanish), Government of Argentina, 23 September 2023, see https://www.argentina.gob.ar/noticias/fideicomiso-para-atucha-i-en-la-agenda-que-impulsa-la-cnv; and NA-SA, "Proyectos Nucleares", Nucleoelectrica Argentina S.A., Undated, see https://www.na-sa.com.ar/es/nuevosproyectos; both accessed 1 November 2023.

1870 - *WNN*, "Atucha 2 receives full operating licence", *World Nuclear News*, 31 May 2016, see http://www.world-nuclear-news.org/RS-Atucha-2-receives-full-operating-licence-3105165.html, accessed 7 May 2021.

1871 - IAEA-PRIS, "Reactor Details—Atucha-2", International Atomic Energy Agency, Updated 19 October 2023, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=5, accessed 20 October 2023.

1872 - ARN, "Parada programada de la Central Nuclear Atucha II", Autoridad Regulatoria Nuclear/Nuclear Regulatory Authority, Government of Argentina, Updated 27 July 2022, see https://www.argentina.gob.ar/arn/parada-programada-de-la-central-nuclear-atucha-ii, accessed 30 October 2023.

1873 - CNEA, "CNEA participó en distintas áreas de trabajo para la entrada en servicio de Atucha II", Press Release (in Spanish), Comisión Nacional de Energía Atómica/National Atomic Energy Commission, Ministry of Economy, Government of Argentina, 30 August 2023, see https://www.argentina.gob.ar/noticias/cnea-participo-en-distintas-areas-de-trabajo-para-la-entrada-en-servicio-de-atucha-ii, accessed 1 November 2023.

1874 - The unit was cleared for restart and reconnected to the grid in late August 2023. See ARN, "La ARN autorizó el regreso al servicio de la Central Nuclear Atucha II", Press Release (in Spanish), Autoridad Regulatoria Nuclear/Nuclear Regulatory Authority, Government of Argentina, 29 August 2023, see https://www.argentina.gob.ar/noticias/la-arn-autorizo-el-regreso-al-servicio-de-la-central-nuclear-atucha-ii; and NA-SA, "Atucha II vuelve a entregar energía luego de una exitosa reparación", Press Release (in Spanish) 29 August 2023, see https://www.na-sa.com.ar/es/prensa/atucha-ii-vuelve-a-entregar-energia-luego-de-una-exitosa-reparacion-354; both accessed 30 October 2023.

Embalse, which started operating in 1983, was shut down at the end of 2015 for major overhaul, including replacing hundreds of pressure tubes, to enable it to operate for up to 30 more years. It eventually returned to service in May 2019.[1875] In August 2019, the regulator (ARN) renewed the operating license for ten years to 2029, after which a safety review will establish "the feasibility of continued operation".[1876]

The current administration has set in motion the recommissioning of the Neuquén heavy water plant by 2025, pledging to invest ARS20 billion (US$90.5 million) to the rehabilitation work expected to span over 25 months.[1877] Heavy water is used as coolant in the country's three operating reactors, but the administration also ambitions to export part of the future production.[1878]

The Atucha-3 Saga, the National Project, and Chinese Ambitions

For the past decade, discussions have been held on the construction of a fourth reactor. In February 2015, Argentina and China ratified an agreement to build an 800-MW CANDU-type reactor at the Atucha site, when Atucha-3 was expected to cost US$5.8 billion.[1879] A framework agreement was also signed in 2015 between the two companies to construct a Hualong One reactor, China's Generation-III design, without a site being specified. In May 2017, a cooperation agreement was signed between Argentina and China, whereby China would help build and mainly finance the construction of the two reactors, with the CANDU-6 starting construction in 2018 and the Hualong reactor in 2020.[1880] However, the site for the Hualong reactor had not been agreed on, as the Governor of Rio Negro—the Government's preferred location—rejected the construction of the reactor in his province, citing a lack of social acceptance for the project.[1881]

The total cost of the Hualong and Atucha-3 projects were expected to be US$12.5 billion (other sources indicate US$15 billion)[1882] financed through a 20-year loan from China at an interest rate of 4.5 percent. In May 2018, the Government announced that it was suspending talks with China regarding the construction of both reactors for at least four years.[1883]

1875 - WNA, "Nuclear Power in Argentina", World Nuclear Association, January 2021, see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx, accessed 7 May 2021.

1876 - ARN, "La ARN otorgó la Licencia de Operación para el segundo ciclo de la Central Nuclear Embalse", Press Release (in Spanish), Autoridad Regulatoria Nuclear/Nuclear Regulatory Authority, 12 September 2019, see https://www.argentina.gob.ar/noticias/la-arn-otorgo-la-licencia-de-operacion-para-el-segundo-ciclo-de-la-central-nuclear-embalse, accessed 23 September 2019.

1877 - Ministry of Economy, "Massa encabezó la firma del convenio para reactivar la planta de agua pesada más grande del mundo", Press Release (in Spanish), Government of Argentina, 15 May 2023, see https://www.argentina.gob.ar/noticias/massa-encabezo-la-firma-del-convenio-para-reactivar-la-planta-de-agua-pesada-mas-grande-0, accessed 1 November 2023.

1878 - *NEI Magazine*, "Argentina reviews prospects for Neuquén heavy water plant", 1 March 2023, see https://www.neimagazine.com/news/newsargentina-reviews-prospects-for-neuqun-heavy-water-plant-10638373, accessed 1 November 2023.

1879 - *WNN*, "Argentina-China talks on new nuclear plants", *World Nuclear News*, 8 May 2015, see https://www.world-nuclear-news.org/Articles/Argentina-China-talks-on-new-nuclear-plants, accessed 17 June 2022.

1880 - CAEA, "CNNC to build heavy water reactor and HPR 1000 units in Argentina", China Atomic Energy Authority, Updated 27 May 2017, see http://www.caea.gov.cn/english/n6759361/n6759362/c6792809/content.html, accessed 17 June 2022.

1881 - Phil Chaffee, "Argentina", *Nuclear Intelligence Weekly*, 29 September 2017.

1882 - *WNN*, "Argentina and China sign contract for two reactors", *World Nuclear News*, 18 May 2017, see http://www.world-nuclear-news.org/NN-Argentina-and-China-sign-contract-for-two-reactors-1805175.html, accessed 7 May 2021.

1883 - Phil Chaffee, "The Fallout From Argentina's Newbuild Retreat", *Nuclear Intelligence Weekly*, 25 May 2018.

In June 2019, the Argentine Government expressed ongoing support for the project following official meetings with their Chinese counterparts, with Argentina's cabinet chief Marcos Pena saying, "there is an intention to move forward."[1884] The President of China National Nuclear Corporation (CNNC) Jun Gu told delegates at an IAEA conference in October 2019 that construction of the reactors would begin in 2020[1885], which did not happen.

In June 2021, the state-owned company Nucleoeléctrica Argentina SA (NA-SA) approved an Action Plan for the coming years.[1886] The plan provided for the construction of a Hualong One reactor and the "preservation of [the] national technology (heavy-water natural-uranium)" through the revival of the CANDU project (see past WNISR editions).[1887] An EPC contract was signed in February 2022, by NA-SA and CNNC for the fourth reactor of the country, Atucha-3, as a 1,200 MWe HPR-1000 or Hualong One reactor with an initial lifetime of 60 years, involving an investment "of over US$8 billion".[1888]

Despite this, the future of the project remains uncertain, and its prospects are further diminished by the ongoing tensions between the U.S. and China, which will likely affect developments in Argentina. The U.S. Department of Defense has identified 20 Chinese companies, including CNNC, as having ties to the Chinese military. In 2020, the China-focused U.S.-based news platform *SupChina* commented: "If Washington decides to pursue sanctions against those firms, that could be the final nail in the coffin of the Argentinian Hualong-1 saga."[1889] The two main companies that have developed the Hualong One, CNNC and China General Nuclear Power Corporation (CGN), were blacklisted by the U.S. Administration.[1890]

It remains unclear what influence the U.S. imposed trade restrictions will have on the plan, but the U.S. administration, as it has successfully done in the U.K,[1891] appears eager to disqualify China from this cooperation. In May 2022, according to NA-SA President José Luis Antúnez, the U.S. again expressed concerns over the possible deal through U.S. State Department representative Ann K. Ganzer during a series of meetings with officials in Argentina, notably

1884 - Cassandra Garrison and Hugh Bronstein, "Argentine official, in China, talks nuclear deal and soymeal", *Reuters*, 25 June 2019, see hhttps://www.reuters.com/article/us-argentina-china-idUSKCN1TQ221, accessed 17 June 2022.

1885 - *WNN*, "China confident of 'new era' for nuclear, says CNNC president", *World Nuclear News*, 9 October 2019, see https://world-nuclear-news.org/Articles/China-confident-of-new-era-for-nuclear-says-CNNC, accessed 7 May 2021.

1886 - Nucleoeléctrica Argentina S.A., "Impulso al desarrollo nuclear: el Poder Ejecutivo Nacional aprobó el Plan de Acción de Nucleoeléctrica Argentina", Press Release (in Spanish), 7 July 2021, see https://portal.na-sa.com.ar/es/prensa/impulso-al-desarrollo-nuclear-el-poder-ejecutivo-nacional-aprobo-el-plan-de-accion-de-nucleoelectrica-argentina-230, accessed 29 July 2021.

1887 - Nucleoeléctrica Argentina, "Plan de acción para Nucleoeléctrica Argentina", *Mercado Eléctrico* (in Spanish), 30 June 2021, see http://www.melectrico.com.ar/web/index.php?option=com_content&view=article&id=3120:plan-de-accion-para-nucleoelectrica-argentina&catid=1:latest-news, accessed 29 July 2021.

1888 - Comisión Nacional de Energía Atómica, "Se firmó el contrato para la construcción de la Central Nuclear Atucha III", 1 February 2022, see https://www.argentina.gob.ar/noticias/se-firmo-el-contrato-para-la-construccion-de-la-central-nuclear-atucha-iii, accessed 9 May 2022; and *WNN*, "China and Argentina sign nuclear project deal", *World Nuclear News*, 2 February 2022, see https://www.world-nuclear-news.org/Articles/China-and-Argentina-sign-nuclear-project-deal, accessed 2 February 2022.

1889 - Álvaro Etchegaray, "Chinese nuclear energy in Argentina is in trouble", *SupChina*, 3 September 2020, see https://supchina.com/2020/09/03/chinese-nuclear-energy-in-argentina-is-in-trouble/, accessed 7 May 2021.

1890 - Bureau of Industry and Security, "Entity List", U.S. Department of Commerce, see https://www.bis.doc.gov/index.php/policy-guidance/lists-of-parties-of-concern/entity-list, accessed 7 July 2021.

1891 - Anna Isaac, "US celebrates 'win' as Britain looks to push China out of nuclear energy sites", *The Independent,* 29 September 2021.

warning over safety concerns raised by the alleged immaturity of the Hualong design and past issues with the technology.[1892]

The concerns raised by the U.S. Administration echo a criminal complaint lodged by environmental activists in March 2022 against Nucleoeléctrica officials "for the probable commission of crimes in public action", and against "those responsible for the probable commissioning of the crimes in an abuse of authority and violation of the duties of a public official" according to the Criminal Code. The complaint, arguing that the contract for the supply of the Hualong One would be illegal because of the design being "experimental, with very little operating experience", was filed before the Federal Prosecutor of Campana in the province of Buenos Aires.[1893]

Argentina's industry executives appear to dismiss this line of argument with NA-SA President José Luis Antúnez contending that Germany and Canada were "irreproachable providers in spite of that, the three machines [Atucha-1 and -2, and Embalse] had problems, and serious ones."[1894] Asked whether she viewed the objections expressed by the U.S. as geopolitical considerations disguised as technical concerns, CNEA President Adriana Serquis confirmed, and replied she had "no doubt" these supposed technological issues were "based on nothing".[1895]

However, following the EPC contract with CNNC, José Luis Antúnez confirmed in April 2022, that both parties still "have to close the financial agreement – the credit details and the disbursement schedule". [1896] Earlier in the month, NA-SA representatives stated that Argentina is pushing China to fully fund the project in order to avoid new delays caused by financial difficulties; a digression from the initial 2014-agreement which foresaw China carrying 85 percent of the funding and Argentina providing the remaining 15 percent.[1897] Argentina's inflation rate has exceeded 70 percent in July 2022[1898] and reached almost twice that rate by September 2023,[1899] making financing of large, long-term projects particularly hazardous.

In April 2022, Antúnez had cited a "maximum term of nine months" to settle and enforce the agreement, indicating expectations that construction would consequently be launched before end of the year and last for eight years,[1900] contractually a 90 months-timeline has been set

1892 - *CE NoticiasFinancieras*, "U.S. lobby to block Argentine nuclear power production", 22 May 2022; and Ajendra Dandan, "El lobby estadounidense para bloquear la producción de energía nuclear argentina", *Página/12* (in Spanish), 22 May 2022, see https://www.pagina12.com.ar/423362-el-lobby-estadounidense-para-bloquear-la-produccion-de-energ, accessed 3 June 2022.

1893 - *La Nueva Mañana*, "Atucha III: denuncian penalmente al Director de Nucleoeléctrica Argentina", 23 March 2022, see https://lmdiario.com.ar/contenido/336964/atucha-iii-denuncian-penalmente-al-director-de-nucleoelectrica-argentina, accessed 11 April 2022.

1894 - *CE Noticias Financieras*, "U.S. lobby to block Argentine nuclear power production", 22 May 2022.

1895 - Gabriel Rocca, "'Alta presión': la visión de Adriana Serquis sobre la postura de EE.UU. en las negociaciones con China", Interview with Adriana Serquis, CNEA President (in Spanish), AgendAR, 21 October 2022, see https://agendarweb.com.ar/2022/10/21/alta-presion-la-vision-de-adriana-serquis-sobre-la-postura-de-ee-uu-en-las-negociaciones-con-china/, accessed 1 November 2023.

1896 - *NEI Magazine*, "Argentina optimistic about nuclear ties with China", *Nuclear Engineering International*, 28 April 2022, see https://www.neimagazine.com/news/newsargentina-optimistic-about-nuclear-ties-with-china-9658784, 17 June 2022.

1897 - Eliana Raszewski, "Argentina wants China to fully fund $8.3 bln nuclear plant amid cash shortfall", *Reuters*, 5 April 2022, see https://www.reuters.com/business/energy/argentina-wants-china-fully-fund-83-bln-nuclear-plant-amid-cash-shortfall-2022-04-05/, accessed 6 April 2022; and *Télam*, "Nucleoeléctrica ratifies negotiation to obtain 100% financing for Atucha III", *CE NoticiasFinancieras*, 12 April 2022.

1898 - Anusha Rathi, "Argentina's Economic Crisis Never Went Away", *Foreign Policy*, 15 August 2022, see https://foreignpolicy.com/2022/08/15/argentina-imf-debt-massa-fernandez/, accessed 23 August 2022.

1899 - *Trading Economics*, "Argentina Inflation Rate", Undated, see https://tradingeconomics.com/argentina/inflation-cpi, accessed 5 November 2023.

1900 - *NEI Magazine*, "Argentina optimistic about nuclear ties with China", 28 April 2022, op. cit.

before first criticality.[1901] In other words, as noted in WNISR2022, Argentina aimed to start construction of a Hualong One at Atucha by late 2022.[1902] However, no agreement was reached, and no construction started.

Instead, in September 2022, it was reported that negotiations encountered new complications with concerns from the Argentinian side regarding fuel supply, insisting that the fuel be produced domestically, which would be a first for a foreign industry to be licensed to manufacture fuel for the Hualong One design. The President of CNEA commented: "We are not claiming to be in an equal position. We are a small economy dealing with one of the world's biggest. Still, they don't have to teach us the basics."[1903] In late 2022, the delay provided by the EPC contract to reach a financial agreement was extended beyond the initial 270 days, until October 2023.[1904]

Thus far, in 2023 the same dynamics remained at play: in April 2023, Argentina's ambassador to China again pleaded with the Chinese Government to finance the entirety of investment,[1905] while the U.S. pursued its relentless attempts to steer Argentina away from the potential cooperation.[1906]

Argentina held general elections in October/November 2023 which could have a significant impact on these joint nuclear projects and the energy sector altogether. Candidate Sergio Massa, the current Economy Minister, can be expected to pursue the approach of the present administration on the matter. Javier Milei, far-right candidate has called for a trade freeze with China.[1907]

Meanwhile, according to NA-SA's 2022-Annual Report, construction on a 700-MW CANDU reactor, which is referred to as "Reactor V" or the "National Project" is still to begin in 2024.[1908] Commercial operation of the unit is expected to begin in 2032.[1909] However, considering all the uncertainty surrounding this project, such a schedule seems highly unrealistic.

1901 - Phil Chaffee, "Atucha-3 EPC Contract Remains Conditional", Interview with José Luis Antúnez, NA-SA, *NIW*, 11 February 2022.

1902 - *NEI Magazine*, "Argentina optimistic about nuclear ties with China", 28 April 2022, op. cit.

1903 - Jonathan Tirone, "Argentina Pauses Nuclear Deal with China over Fuel Sourcing for Power Plant", *Bloomberg*, 19 September 2022, see https://www.bloomberglinea.com/english/argentina-pauses-nuclear-deal-with-china-over-fuel-sourcing-for-power-plant/, accessed 1 November 2023.

1904 - Nicolás Deza, "Nucleoeléctrica prorrogó el contrato comercial por Atucha III a la espera de una definición política sobre el proyecto", *Econo Journal* (in Spanish), 13 December 2022, see https://econojournal.com.ar/2022/12/nucleoelectrica-prorrogo-el-contrato-comercial-por-atucha-iii-a-la-espera-de-una-definicion-politica-sobre-el-proyecto/, accessed 1 November 2023.

In October 2023, the contract was further extended to April 2025; see Nicolás Deza, "El gobierno prorrogó otra vez el contrato de Atucha III", *Econo Journal*, 21 October 2023 (in Spanish), see https://econojournal.com.ar/2023/10/en-medio-de-la-negociacion-con-china-por-el-swap-el-gobierno-prorrogo-otra-vez-el-contrato-de-atucha-iii/, accessed 1 November 2023.

1905 - *Télam*, "Vaca Narvaja pidió a China que financie la construcción de Atucha III", 25 April 2023, see https://www.telam.com.ar/notas/202304/626476-atucha-iii-nuclear-china-vaca-narvaja.html, accessed 1 November 2023.

1906 - Raúl Dellatorre, "Ofensiva para desconectar a la Argentina de China", *Página12*, 9 April 2023 (in Spanish), see https://www.pagina12.com.ar/538896-ofensiva-para-desconectar-a-la-argentina-de-china, accessed 1 November 2023.

1907 - Walter Brandimarte and Manuela Tobías, "Argentina's Milei Floats Plans to Freeze Trade With China, Abandon Mercosur", *Bloomberg, 16 August 2023, see* https://www.bloomberglinea.com/english/argentinas-milei-floats-plans-to-freeze-trade-with-china-abandon-mercosur/, accessed 1 November 2023.

1908 - NA-SA, "Reporte Integrado 2022", Nucleoeléctrica Argentina S.A., July 2023, see https://www.na-sa.com.ar/storage/files/shares/informe%20PG%202022pdf.pdf, accessed 31 October 2023.

1909 - IAEA, "Country Nuclear Power Profiles—2022 Edition—Argentina", Updated 2022, see https://cnpp.iaea.org/countryprofiles/Argentina/Argentina.htm, accessed 1 November 2023.

It is not clear at the time of writing, in October 2023, where the unit is to be located since Atucha-3 is still destined to host the Hualong One reactor and Embalse has seemingly been disqualified.[1910] In fact, NA-SA's annual report specifies that the assessment of potential providers and locations, as well as the scope of necessary help from the original designer (SNC-Lavalin) remain to be performed; and further states:

> Given the current conditions of the country, the significant projects (fourth and fifth nuclear power plants) are at a minimum state of progress and it was not possible to meet some of the objectives set by the Company. This fact had negative impacts such as the generation of quality work that was programmed.[1911]

Moreover, no financing has been secured, and there are no indications that talks on the financing of the CANDU reactor are truly underway, let alone a deal anywhere close to being struck.

CAREM-25 Construction Still in Limbo

Construction of a prototype 25-MWe PWR, the domestically designed CAREM-25 (Central Argentina de Elementos Modulares—a pressurized-water SMR) began near the Atucha site in February 2014, with startup planned for 2018. In 2005, CNEA, in charge of the project, had estimated that the construction would cost US$105 million,[1912] but by construction start in 2014 estimates had risen to US$446 million.[1913] In 2019, it was rescheduled to begin operating in 2022.[1914] This did not happen.

In early June 2022, CAREM project manager, Sol Pedre revealed in an interview that concreting had restarted in January 2022 advancing civil work to 72 percent completion. He also announced that the current schedule aims for a 2027-startup.[1915] While an updated cost estimate is not available, Sol Pedre implied that the overall budget is at least US$520 million, by pointing out that fabricating the pressure vessel "has already taken [US]$52 million from the project, which is roughly 10% of the total budget".[1916] In 2021, a non-profit organization established by the Group of Twenty (G20), GI Hub, reported their own estimate at US$750 million.[1917] Even at the lower cost estimate of US$520 million, the per unit cost of the project would be at around US$17,000/kW, roughly twice the cost estimate of the most expensive Generation-III reactors.

1910 - Phil Chaffee, "Interview: Antunez Explains Argentina's Current Newbuild Plans", Interview with Jose Luis Antunez, NA-SA President, *Energy Intelligence*, 29 November 2021, see https://www.energyintel.com/0000017d-4991-d7ef-a3ff-59dfac290000, accessed 2 November 2023.

1911 - NA-SA, "Reporte Integrado 2022", Nucleoeléctrica Argentina S.A., July 2023, op. cit.

1912 - IAEA, "Technology Roadmap for Small Modular Reactor Deployment", August 2021, see https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1944_web.pdf, accessed 4 July 2022.

1913 - *WNN*, "Construction of CAREM underway", *World Nuclear News*, 10 February 2014, s ee http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2021.

1914 - *Agencia TSS*, "CAREM: Reactor en alta tensión", 21 February 2019, see http://www.unsam.edu.ar/tss/carem-reactor-en-alta-tension/, accessed 26 June 2021.

1915 - *Agencia TSS*, "Sol Pedre: 'El CAREM es un salto cualitativo para el sector nuclear argentino'", 2 June 2022, see https://www.unsam.edu.ar/tss/sol-pedre-el-carem-es-un-salto-cualitativo-para-el-sector-nuclear-argentino/, accessed 18 June 2022.

1916 - Ibidem.

1917 - GIH, "Case Studies—Carem 25 (prototype)", Global Infrastructure Hub, 25 January 2021, see https://www.gihub.org/quality-infrastructure-database/case-studies/carem-25-prototype/, accessed 18 August 2022.

In October 2022, the President of CNEA, Adriana Serquis, stated that civil works were expected to be completed by the end of 2024, and first criticality reached by the end of 2027.[1918]

By May 2023, civil works were said to have progressed to 78 percent completion, while overall construction remained at 62 percent.[1919]

Power Mix and Current Policies

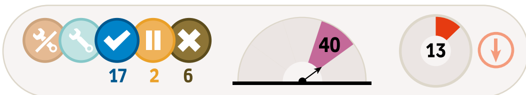
According to the Energy Institute, in 2022, Argentina's electricity generation was largely dominated by natural gas (53 percent), followed by hydro (15 percent), non-hydro renewables (13 percent), oil (11 percent), nuclear (5 percent) and coal (1.4 percent).[1920]

According to IRENA, renewable capacity grew by only 56 MW in 2022, to reach 15 GW.[1921] A major hinderance to the deployment of further renewable capacity appears to be inadequate infrastructure, with EY's "Renewable Energy Country Attractiveness Index" downgrading Argentina from rank 26 to 30, with the explanation that the country is "committed to growing renewables, but its energy grid is thought to be insufficient to support a further significant rollout of renewables capacity, with recent investment in generating capacity not matched by infrastructure."[1922]

Brazil

See Focus Countries – Brazil Focus.

Canada



Canada operates 19 CANDU reactors with a total capacity of 13.6 GW. Refurbishment of two units (Bruce-6 and Darlington-3) started in 2020, leaving 17 reactors in operation during the 2022–23 period that we report on here. According to the PRIS database, these produced 81.72 TWh in 2022, which constituted 12.9 percent of total electricity generation in Canada. Both have declined from the 2021 figures of 86.78 TWh and 14.3 percent respectively. Eighteen out of the 19 nuclear reactors are located in the province of Ontario, where nuclear power contributed 54 percent of the electricity generated in 2022, down from 58 percent in 2021.[1923]

1918 - *Télam*, "El Carem es «un proyecto muy importante» en el desarrollo de la energía nuclear", 18 October 2022 (in Spanish), see https://www.telam.com.ar/notas/202210/608183-director-oiea-carem-proyecto-energia-nuclear.html, accessed 2 November 2023.

1919 - Ministry of Economy, "El Presidente de la Nación visitó las obras del reactor nuclear CAREM en Lima", Press Release (in Spanish), Government of Argentina, 5 May 2023, see https://www.argentina.gob.ar/noticias/el-presidente-de-la-nacion-visito-las-obras-del-reactor-nuclear-carem-en-lima, accessed 2 November 2023.

1920 - Energy Institute, "Statistical Review of World Energy 2023—Data", June 2023, see https://www.energyinst.org/statistical-review, accessed July 2023.

1921 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, 2023, see https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf?rev=d2949151ee6a4625b65c82881403c2a7, accessed 30 July 2023.

1922 - EY, "Renewable Energy Country Attractiveness Index (RECAI)—61 Edition", Ernst & Young, June 2023, see https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/power-and-utilities/ey-recai-61-report.pdf, accessed 2 November 2023.

1923 - IESO, "IESO Year-End Data—2022 Year in Review", Independent Electricity System Operator, 2023, see https://ieso.ca/en/Corporate-IESO/Media/Year-End-Data#yearenddata, accessed 11 June 2023.

Refurbishment

Canada is in the process of refurbishing many of its ageing CANDU reactors, which "involves replacing crucial components such as pressure tubes, which have reached the end of their service lives" with as "many as 2,000 OPG employees and contractors" working at just the Darlington site.[1924] As mentioned, two of them (Bruce-6 and Darlington-3) have been going through the process since 2020. Darlington-3 was reconnected to the grid in mid-July 2023.[1925] Refurbishment of Darlington-2 has been completed with a delay of around four months as detailed in WNISR2020. The refurbishment of Darlington-1 commenced in February 2022 (anticipated completion Q2 2025), while Darlington-4 commenced on 2 July 2023 (anticipated completion Q4 2026).[1926] The projects at Darlington have not proceeded according to the schedule laid out in IESO's annual planning document from January 2020; the dates mentioned in that document for completion of refurbishment were 15 December 2024, 15 June 2023, and 31 May 2026 for Darlington-1, Darlington-3, and Darlington-4 respectively.[1927] (See Table 27).

In the case of the Bruce station, Unit 6 was removed from service in January 2020[1928] and Unit 3 was shut down on 1 March 2023.[1929] According to the Ontario IESO's annual planning document from December 2022, Bruce-6 is to restart in November 2023 and Bruce-3 in December 2026.[1930] The others are scheduled for refurbishment only in the future (see Table 27). Some of these dates have been pushed backward in comparison to the dates expected in IESO's annual planning document from January 2020.

The only nuclear power plant that was not scheduled to be refurbished is the Pickering plant with six operating reactors. However, in September 2022, the Ontario government announced that it supported Ontario Power Generation's (OPG's) plan to continue operating the Pickering reactors up until September 2026,[1931] beyond their currently envisioned shutdown dates between September 2024 and December 2025.[1932] According to the September 2022 announcement, the "Pickering "A" units 1 and 4 would operate until 2024, and Pickering "B" units 5 through 8 would operate until September 2026". The Ontario government also requested OPG to "update its feasibility assessment for refurbishing Pickering "B" units at the Nuclear Generating

1924 - Matthew McClearn, "Upgrades at this aging nuclear plant are complicated, critical and, so far, surprisingly successful", *The Globe and Mail*, 15 July 2023, see https://globe2go.pressreader.com/article/281479280887515, accessed 16 July 2023.

1925 - OPG, "OPG celebrates the early completion of Darlington Unit 3", Press Release, Ontario Power Generation, 18 July 2023, see https://www.opg.com/media_releases/opg-celebrates-the-early-completion-of-darlington-unit-3/, accessed 19 July 2023.

1926 - IESO, "Annual Planning Outlook—Ontario's electricity system needs: 2024-2043", Independent Electricity System Operator, December 2022, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Dec2022/2022-Annual-Planning-Outlook.ashx, accessed 29 July 2023.

1927 - IESO, "Annual Planning Outlook—A view of Ontario's Electricity System Needs", Independent Electricity System Operator, January 2020, p.11, see http://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Jan2020.pdf?la=en, accessed 29 July 2023.

1928 - Bruce Power, "Unit 6 MCR construction complete on-time and on-budget, focus shifts to return to service", Bruce Power, 4 May 2023, see https://www.brucepower.com/2023/05/04/unit-6-mcr-construction-complete-on-time-and-on-budget-focus-shifts-to-return-to-service/, accessed 29 July 2023.

1929 - Bruce Power, "Bruce Power begins Unit 3 Major Component Replacement outage", Bruce Power, 2 March 2023, see https://www.brucepower.com/2023/03/02/bruce-power-begins-unit-3-major-component-replacement-outage/, accessed 29 July 2023.

1930 - IESO, "Annual Planning Outlook—Ontario's electricity system needs: 2024-2043", December 2022, op. cit., p.33.

1931 - Government of Ontario, "Ontario Supports Plan to Safely Continue Operating the Pickering Nuclear Generating Station", Press Release, 29 September 2022, see https://news.ontario.ca/en/release/1002338/ontario-supports-plan-to-safely-continue-operating-the-pickering-nuclear-generating-station, accessed 29 July 2023.

1932 - IESO, "Annual Planning Outlook - Ontario's electricity system needs: 2024-2043", December 2022, op. cit.

Station" that would result in "an additional 30 years" of operations at the facility. Using the freedom of information law, *Global News* revealed that by keeping Pickering operational, the Ontario government also desired "to give environmentally conscious Ontarians the impression it was attempting to counter the increase in greenhouse gas emissions from more natural gas generation".[1933] In June 2023, OPG submitted "an application to extend commercial operation of Units 5–8 at the Pickering Nuclear Generation Station until December 31, 2026, as the current license "does not allow commercial operation beyond December 31, 2024".[1934]

Table 27 · Status of Canadian Nuclear Fleet - PLEX and Expected Closures

Reactor	Operator	Grid Connection	Refurbishment[a] (Provisional Jan. 2020)	Planned Closure[b]	Licensed to[c]
Bruce-1	Bruce Power	1977	Restarted in 2012	2064	2028
Bruce-2		1976	Restarted in 2012		
Bruce-3		1977	01/02/23[d]–11/12/26 (01/01/23–30/06/26)		
Bruce-4		1978	01/01/25–31/12/27		
Bruce-5		1984	01/10/26–30/09/29 (01/07/26–30/06/29)		
Bruce-6		1984	17/01/20–04/11/23 (01/01/20–19/10/23)		
Bruce-7		1986	01/07/28–30/06/31		
Bruce-8		1987	01/10/30–30/09/33 (01/07/30–30/06/23)		
Darlington-1	OPG	1990	15/02/22–17/04/25 (15/10/21–15/12/24)	2055	2025
Darlington-2		1990	10/16–06/20[e]		
Darlington-3		1992	30/07/20–04/09/23[f] (15/02/20–15/06/23)[g]		
Darlington-4		1993	02/07/23[h]–01/08/26 (01/05/23–31/05/26)		
Pickering-1	OPG	1971		End 2024[i]	2028[k]
Pickering-4		1973		End 2024[i]	
Pickering-5		1982		30/09/2026[j]	
Pickering-6		1983		30/09/2026[j]	
Pickering-7		1984		30/09/2026[j]	
Pickering-8		1986		30/09/2026[j]	
Point Lepreau	NB Power	1982	03/2008–03/2012	2039–2040[l]	2032[m]

Sources: compiled by WNISR, with IESO, Operators and CNSC, 2023

Notes: **OPG**: Ontario Power Generation

a - IESO, "Annual Planning Outlook - Ontario's electricity system needs: 2024-2043", December 2022.

When different provisional dates from IESO, "Annual Planning Outlook - A view of Ontario's electricity system needs", January 2020, see http://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Jan2020.pdf?la=en, accessed 1 August 2020.

b - As announced by operator.

1933 - Colin D'Mello and Isaac Callan, "Time running out for Ontario to formally request Pickering nuclear power station extension", *Global News*, 30 May 2023, see https://globalnews.ca/news/9730549/pickering-nuclear-power-station-extension-deadline-approaching/, accessed 29 July 2023.

1934 - CNSC, "Pickering Nuclear Generating Station", Canadian Nuclear Safety Commission, 27 June 2023, see https://www.nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm, accessed 29 July 2023.

c - As listed on Canadian Nuclear Safety Commission's (CNSC) website for each station, as of 31 August 2023.

Bruce: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/bruce-nuclear-generating-station/index.cfm;

Darlington: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/darlington-nuclear-generating-station/index.cfm;

Pickering: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm;

Point Lepreau: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/point-lepreau-nuclear-generating-station/index.cfm.

d – Bruce-3 refurbishment started on 1 March 2023. Bruce Power, "Bruce Power begins Unit 3 Major Component Replacement outage", 2 March 2023.

e - Refurbishment of Darlington-2 was completed in June 2020, with the reactor being reconnected to the grid on 2 June 2020; see OPG, "Darlington Unit 2 powers on—Refurbishment now complete on first unit", 4 June 2020, see https://www.opg.com/news/darlington-unit-2-powers-on/, accessed 28 July 2020.

f – Refurbishment of Darlington-3 was completed in July 2023, with the reactor being reconnected to the grid on 17 July 2023.

OPG, "OPG celebrates the early completion of Darlington Unit 3", Ontario Power Generation, 18 July 2023, see https://www.opg.com/media_releases/opg-celebrates-the-early-completion-of-darlington-unit-3/, accessed 19 July 2023.

g - In the December 2020 issue of the IESO outlook the dates were changed to 30/07/2020–02/01/2024.

IESO, "Annual Planning Outlook - Ontario's electricity system needs: 2022-2040", Independent Electricity System Operator, December 2020, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Dec2020.ashx.

h - Darlington-4 was removed from service on 19 July 2023, see OPG, "Darlington Refurbishment is a made-in-Ontario success story", 9 August 2023, see https://prdopgv2.wpengine.com/releases/darlington-refurbishment-is-a-made-in-ontario-success-story/, accessed 31 August 2023.

Expected completion date is 4th Quarter of 2026, see OPG, "Darlington Refurbishment performance update - Q1 2023", OPG, 20 June 2023, see https://www.opg.com/news/darlington-refurbishment-performance-update-q1-2023/, accessed 16 July 2023.

i - OPG, "Pickering Nuclear Station", n.d., see https://prdopgv2.wpengine.com/power-generation/our-power/nuclear/pickering-nuclear/, accessed 31 August 2023.

j - OPG, "Pickering Nuclear Generating Station – Power Reactor Operating Licence Amendment Application", Letter to Canadian Nuclear Safety Commission, Ontario Power Generation, 16 June 2023, see https://www.opg.com/documents/letter-to-cnsc-re-pickering-licence-amendment-application-pdf/, accessed 16 July 2023.

k - The current Pickering Power Plan license will expire in 2028, but does not allow operation beyond 2024. OPG's application requires a public hearing and authorization from the Commission; as of 1 September 2023, a date for this hearing had not yet been set.

See CNSC, "Pickering Nuclear Generating Station", Updated 27 June 2023, see https://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm, accessed 16 July 2023.

l - NB Power, "NB Power's 10-Year Plan - Fiscal Years 2021 to 2030", September 2019, see https://www.nbpower.com/media/1489656/10-year-plan-2021-to-2030.pdf, accessed 13 May 2020; and updated with NB Power, "Integrated Resource Plan", November 2020, see https://www.nbpower.com/media/1490323/2020-irp-en-2020-11-17.pdf, accessed July 2021.

m - CNSC, "CNSC renews the power reactor operating licence for the Point Lepreau Nuclear Generating Station for a 10-year period", Canadian Nuclear Safety Commission, Updated 22 June 2022, see https://www.canada.ca/en/nuclear-safety-commission/news/2022/06/cnsc-renews-the-power-reactor-operating-licence-for-the-point-lepreau-nuclear-generating-station-for-a-10-year-period.html, accessed 23 June 2022.

Other Updates

In April 2023, there was a leak of tritiated heavy water from the Bruce-4 reactor, which "reached a drain and potentially made its way into Lake Huron".[1935] According to the Canadian Nuclear Safety Commission's Event Report, Bruce Power "estimated that the total amount of heavy water that leaked" was 135 Mg (or 135 tons); nearly 180 workers were involved in the initial event response and subsequent clean up and mitigation efforts.[1936] Bruce Power also estimated the tritium release to Lake Huron to be 9.26 X 10^{11} Bq.

In July 2023, Ontario's government announced plans to "build up to 4800 MWe of new nuclear capacity" at the Bruce site.[1937] The announcement did not specify what kind of reactors would be built. Nor was there any mention of the estimated cost, the main reason for the failure of the earlier effort to build large reactors. In 2008, when the Ontario government called upon

1935 - Eric Thompson, "'No adverse impacts' from Bruce Power leak", *CKNX News Today*, 12 June 2023, see https://cknxnewstoday.ca/news/2023/06/12/no-adverse-impacts-bruce-power-leak, accessed 18 June 2023.

1936 - CNSC, "Event Initial Report: Bruce Power—Bruce A Unit 4 Heat Transport Purification System Heavy Water Leak", Canadian Nuclear Safety Commission, June 2023, see https://www.nuclearsafety.gc.ca/eng/the-commission/meetings/cmd/pdf/CMD23/CMD23-M20.pdf accessed 20 August 2023.

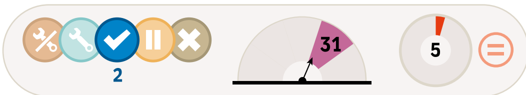
1937 - *WNN*, "Ontario government announces support for nuclear expansion", *World Nuclear News*, 6 July 2023, see https://world-nuclear- news.org/Articles/Ontario-government-announces-support-for-nuclear-e, accessed 6 July 2023.

reactor vendors to bid for the construction of two more reactors at the Darlington site, Atomic Energy of Canada Limited's bid was reported to be CAD$26 billion (US$ $_{2008}$24.4 billion) for two 1200 MW CANDU reactors, more than thrice the amount that the government had assumed in its plans, leading the government to abandon the effort to construct new reactors.[1938]

Federal government agencies and some provincial governments, continue to promote the development of Small Modular Reactors (see chapter on SMRs – Canada).

Total renewable energy capacity (incl. hydro) in Canada as of 2022 amounted to 105.8 GW, an increase of 2.5 percent compared to 2021, growing from 86.8 GW a decade ago (i.e., 2013). The bulk of renewable capacity is hydropower which constituted 83.6 GW in 2022, up from 75.5 GW in 2013; during the same period, wind energy capacity almost doubled from 7.8 GW to 15.3 GW, and solar energy capacity more than tripled from 1.2 GW to still modest 4.4 GW.[1939] In 2022, wind energy contributed 39.1 TWh and solar energy contributed 3.2 TWh respectively.[1940] Together with hydro power, which contributed 392.3 TWh, renewables contributed over two thirds of all electrical energy generated in Canada.

Mexico



Laguna Verde, located in Alto Lucero, Veracruz, is the only nuclear power plant in Mexico. Two General Electric (GE) Boiling Water Reactors (BWRs) operate there, with the first unit connected to the grid in 1989 and the second unit in 1994. A US$600 million upgrading project was launched in 2007 to increase output of both units by 20 percent. It was completed in 2011,[1941] bringing the plant's net capacity to 1.55 GW.[1942] The plant is owned and operated by the state utility Comisión Federal de Electricidad (Federal Electricity Commission) commonly referred to as CFE. In 2022, both units underwent refueling outages[1943] that caused a drop in nuclear production to 10.5 TWh which represented 4.5 percent of the country's total electricity production, down from 11.6 TWh and 5.3 percent in 2021.[1944]

1938 - Tyler Hamilton, "$26B cost killed nuclear bid", *The Toronto Star*, 14 July 2009, see http://www.thestar.com/business/2009/07/14/26b_cost_killed_nuclear_bid.html; and Keith Leslie, "Ontario nixes building two nuclear reactors; will rebuild existing reactors", *The Canadian Press* as published by *Global News*, 10 October 2013, see http://globalnews.ca/news/894709/ontario-nixes-building-two-nuclear-reactors/; both accessed 23 August 2023.

1939 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 29 July 2023.

1940 - Statistics Canada, "Electric power generation, monthly generation by type of electricity", Government of Canada, 17 June 2023, see https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501, accessed 17 June 2023.

1941 - *WNN*, "More capacity for Laguna Verde", *World Nuclear News*, 7 February 2011, see https://www.world-nuclear-news.org/Articles/More-capacity-for-Laguna-Verde, accessed 2 June 2022.

1942 - PRIS, "Country Statistics—Mexico", International Atomic Energy Agency, Updated 12 May 2022, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=MX, accessed 2 June 2022.

1943 - CFE, "Informe Anual 2022", Comisión Federal de Electricidad/ Federal Electricity Commission (in Spanish), April 2023, see https://infosen.senado.gob.mx/sgsp/gaceta/65/2/2023-04-28-1/assets/documentos/SEGOB_Informe_Anual_CFE_2022.pdf, accessed 6 July 2023.

1944 - All numbers are from IAEA-PRIS data. According to the Mexican Ministry of Energy (SENER) data, nuclear generated 10.6 TWh and represented 3.1 percent of the total production of electricity; see SENER, "Programa para el Desarrollo del Sistema Eléctrico Nacional 2023–2037", Secretaría de Energía/Ministry of Energy, Government of Mexico (in Spanish), 29 May 2023, see https://www.gob.mx/sener/articulos/programa-de-desarrollo-del-sistema-electrico-nacional-2023-2037, accessed 1 June 2022. It is unclear why the nuclear share number differs significantly from the number communicated to the IAEA.

In 2015, CFE applied for an unusual 30-year lifetime extension to allow for the two reactors to operate for a total of 60 years. In most countries, lifetime extensions are either by 10-year periods (like in Belgium or France) or in 20-year periods (like in Japan or the U.S.). In March 2019, the IAEA completed a Safety Aspects of Long-Term Operation (SALTO) review mission at the plant and made recommendations as part of the process to prepare for lifetime extension.[1945] The license renewal was granted in July 2020 to allow for the operation of Unit 1 until July 2050.[1946]

At the time of the 2019-IAEA mission, plant management requested for a SALTO follow-up mission to be scheduled for 2021,[1947] the mission took place on 21–24 June 2022.[1948] The team noted that further work was necessary at the plant to "perform a comprehensive periodic safety review to identify potential safety improvements" for long-term operation and to "fully implement a programme to confirm resistance of electrical components to harsh conditions, a so-called equipment qualification programme".[1949] The license for Unit 2—initially set to expire in April 2025—was extended in August 2022 by the Ministry of Energy, allowing the reactor to run until April 2055.[1950]

In 2022, the IAEA identified Argentina, India, and Mexico among the countries where nuclear sites "did not report production disruptions due to weather and water conditions prior to 2000, but have suffered both more frequent outages and higher average production losses since this time."[1951]

There is currently no ongoing reactor construction or formal newbuild project in Mexico, though there have been several initiatives and announcements over the years (see previous WNISR editions). Mexico's "Climate Change Mid-Century Strategy" submitted to the United Nations in 2016, set the goal of at least 50 percent energy generation from clean energy sources by 2050 and suggests "to consider, among the plans for diversification of generating facilities, the implementation of a nuclear program as a possible substitute to fossil fuel use".[1952]

1945 - IAEA, "SALTO Mission to Laguna Verde—Mission Report—Executive Summary", International Atomic Energy Agency, 5 March 2019, see https://www.iaea.org/sites/default/files/documents/review-missions/41_laguna_verde_salto_executive_summary.pdf, accessed 20 October 2023.

1946 - SENER, "La Secretaría de Energía renueva la licencia de operación a Unidad 1 de la Central Nuclear Laguna Verde", Secretaría de Energía/Ministry of Energy, Government of Mexico (in Spanish), 17 July 2020, see http://www.gob.mx/sener/articulos/la-secretaria-de-energia-renueva-la-licencia-de-operacion-a-unidad-1-de-la-central-nuclear-laguna-verde?idiom=es, accessed 7 May 2021.

1947 - IAEA, "IAEA Concludes Long Term Operational Safety Review at Mexico's Laguna Verde Nuclear Power Plant", Press Release 9/2019, 14 March 2019, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-mexicos-laguna-verde-nuclear-power-plant, accessed 5 May 2022.

1948 - IAEA, "IAEA Concludes Long Term Operational Safety Review at Mexico's Laguna Verde Nuclear Power Plant", Press Release 114/2022, 27 June 2022, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-mexicos-laguna-verde-nuclear-power-plant-0, accessed 9 July 2022.

1949 - Ibidem.

1950 - CFE, "La Central Nucleoeléctrica Laguna Verde Refrenda Su Compromiso Con El Medio Ambiente y La Seguridad Energética de México, al Obtener La Extensión de Licencia de Operación De Su Unidad 2 Por 30 Años Más", Press Release (in Spanish), Comisión Federal de Electricidad/Federal Electricity Commission, 25 August 2022, see https://app.cfe.mx/Aplicaciones/OTROS/Boletines/boletin?i=2634, accessed 22 June 2023.

1951 - IAEA, "Climate Change and Nuclear Power 2022—Securing Clean Energy for Climate Resilience", International Atomic Energy Agency, 2022, see https://www.iaea.org/sites/default/files/iaea-ccnp2022-body-web.pdf, accessed 27 June 2023.

1952 - SERMANAT and INECC, "Mexico's Climate Change Mid-Century Strategy", First Edition, Secretaría de Medio Ambiente y Recursos Naturales /Ministry of Environment and Natural Resources, Instituto Nacional de Ecología y Cambio Climático/National Institute of Ecology and Climate Change, submitted to UN Climate Change on 16 November 2016, see https://unfccc.int/files/focus/long-term_strategies/application/pdf/mexico_mcs_final_cop22nov16_red.pdf, accessed 27 June 2023.

The government has regularly promoted such newbuild programs and claimed to be working on various technical options, including a Small Modular Reactor (SMR) in Sonora or Baja California (see earlier WNISR editions). Observers remain more skeptical. As early as 2016, the country's National Institute for Nuclear Research stated in a presentation on SMRs:

- Per kWe capital costs of SMRs are tens to hundreds of percent higher than for large reactors, impacting the Levelised Cost Of Electricity (LCOE) (NEA).
- Difficult to justify investment even if total overnight costs are lower.[1953]

In a "Trend Analysis" of Mexico's energy sector published in March 2022, rating agency Fitch labeled the country's nuclear future as "uncertain", mentioning "we expect no new nuclear capacity additions from 2022 to 2031, with total installed nuclear capacity to remain at 1.6 GW."[1954] And in July 2022, Moody's downgraded CFE from Baa1 to Baa2 (lower medium grade).[1955]

Even so, in September 2022, CFE Director of operations, Carlos Andrés Morales Mar, stated his company's intention to double the share of nuclear power in the country's electricity mix by 2030, bringing it "from 4 to 8 percent",[1956] and in the latest Annual Report that in the "long term", CFE is considering the "incorporation of 5,400 MW of nuclear power plants" to meet the country's rising electricity demand.[1957] Considering the current project status, delivering by 2030 appears materially impossible.

So far, these ambitions are also not reflected in the country's policies and official strategy, in fact estimated addition of nuclear capacity and production increases derived from future newbuild projects have been gradually declining over the years. Mexico's updated NDC submitted in November 2022—wherein the country commits to the addition of 40 GW of clean energy by 2030, but sets no Net Zero target—does not mention nuclear.[1958] Neither did the previous NDC, submitted in 2020.[1959] While, in the longer-term, the latest annual "Program for the Development of the National Electricity System" (PRODESEN) released in May 2023[1960],

1953 - Juan Ramon Mota, "Issues to consider for the implementaion of SMR technology in Mexico", National Institute for Nuclear Research, October 2016, see https://nucleus.iaea.org/sites/INPRO/df13/Presentations/020_Implementing%20New%20Reactor%20Technologies%20in%20Mexico.pdf, accessed 20 October 2023.

1954 - Fitch Solutions, "Industry Trend Analysis - Natural Gas Remains Mexico's Dominant Power Type Amid Nuclear And Non-Hydro Uncertainties", Fitch Solutions Industry Research Reports, 15 March 2022.

1955 - *Reuters*, "Moody's downgrades Mexican CFE power utility to Baa2; changes outlook to stable", 12 July 2022, see https://www.reuters.com/article/mexico-cfe-idUKE1N2U401V, accessed 5 July 2023.

1956 - Arturo Solís, "CFE duplicará el uso de energía nuclear en México hacia 2030", *Bloomberg Línea*, 8 September 2022 (in Spanish), see https://www.bloomberglinea.com/2022/09/08/cfe-duplicara-el-uso-de-energia-nuclear-en-mexico-hacia-2030/, accessed 20 October 2023.

1957 - CFE, "Informe Anual 2022", Comisión Federal de Electricidad, April 2023, see https://infosen.senado.gob.mx/sgsp/gaceta/65/2/2023-04-28-1/assets/documentos/SEGOB_Informe_Anual_CFE_2022.pdf, accessed 20 October 2023.

1958 - SEMARNAT and INECC, "Contribución Determinada a nivel Nacional—Actualización 2022", Secretaría de Medio Ambiente y Recursos Naturales/Ministry of Environment and Natural Resources, Instituto Nacional de Ecología y Cambio Climático/National Institute of Ecology and Climate Change, Government of Mexico, submitted 17 November 2022 (in Spanish), see https://unfccc.int/sites/default/files/NDC/2022-11/Mexico_NDC_UNFCCC_update2022_FINAL.pdf?download, accessed 28 June 2023.

1959 - SEMARNAT and INECC, "Contribución Determinada a nivel Nacional—Actualización 2020", Secretaría de Medio Ambiente y Recursos Naturales/Ministry of Environment and Natural Resources, Instituto Nacional de Ecología y Cambio Climático/National Institute of Ecology and Climate Change, Government of Mexico, submitted 30 December 2020 (in Spanish), see https://unfccc.int/sites/default/files/NDC/2022-06/NDC-Esp-30Dic.pdf, accessed 3 July 2023.

1960 - SENER, "Programa de Desarrollo del Sistema Eléctrico Nacional 2023-2037", Secretaría de Energía/Ministry of Energy, Government of Mexico, May 2023, see http://www.gob.mx/sener/en/articulos/programa-de-desarrollo-del-sistema-electrico-nacional-2023-2037, accessed 8 September 2023.

projects nuclear will contribute 0.32 percent of total capacity added between 2027 and 2037—versus 37.1 percent of solar PV, 8.65 percent for wind and 8.7 percent for hydro. These assumptions are based on the "Indicative Program for the installation and decommissioning of Power Plants" (PIIRCE 2023-2037) which considers a "150 MW of nuclear capacity addition" over that period, relying on the expectation that smaller nuclear units will become affordable for deployment in Mexico.

In the meantime, over the four years 2023–2026, 6.3 GW of Combined Cycle Natural Gas capacity are expected to be connected to the grid—versus 720 MW of solar PV and 487 MW of hydro, and no wind power. A few days before the release of the plan, the Mexican energy regulator, Comisión Reguladora de Energía (CRE), redefined "clean energies" to include co-generation plants fueled by natural gas.[1961] With this calculation, the new "clean energies" made up 31.2 percent of electric power generation in 2022, according to PRODESEN. So, although past year PRODESEN had clarified that the country would not meet its 2024-target of 35 percent of "clean energy",[1962] Mexico will likely accomplish this goal *on paper*.

These target shares of "clean energy"—nuclear power included—in the total electricity production were set by the Energy Transition Act promulgated under the previous administration. The goal was 30 percent for 2021 with 29.5 percent achieved—including 3.5 percent nuclear—and remains 35 percent in 2024.[1963] SENER's updated "Transition Strategy to Promote the Use of Cleaner Technologies and Fuels" published in August 2022, maintains a share of 35.1 percent of clean energy in the total electricity production by 2024, 39.9 percent by 2033 and 55 percent by 2050.[1964]

The current Government's policy has revolved around creating favorable conditions for the state-owned energy enterprises, thereby championing the development of fossil fuel infrastructure in the name of energy sovereignty.1965 It has also long sought to block foreign investment, consequently undermining renewable projects, including by stalling the issuance of operation permits1966 or canceling auctions.1967 According to the *New York Times*, as of June 2022, more than fifty wind and solar projects—representing close to 7 GW—were awaiting permits, some since 2019.[1968]

1961 - Ibidem, and Adriana Barrera, "Mexico energy regulator gives natural gas 'clean' label, drawing criticism", *Reuters*, 30 May 2023, see https://www.reuters.com/business/energy/mexico-energy-regulator-gives-natural-gas-clean-label-drawing-criticism-2023-05-27/, accessed 2 June 2023.

1962 - Thomas Monteiro, "Mexico: Renewable On Hold", *Global Finance*, 5 October 2022, see https://www.gfmag.com/magazine/october-2022/mexico-renewables-on-hold, accessed 3 July 2023.

1963 - Chamber of Deputies, "Ley de Transición Energética", Congress of the Union of the United Mexican States, promulgated 24 December 2015 (in Spanish), see https://www.diputados.gob.mx/LeyesBiblio/pdf/LTE.pdf, accessed 27 June 2023.

1964 - SENER, "Reporte Anual del Potencial de Mitigación de Gei del Sector Eléctrico", Secretaría de Energía/Ministry of Energy, Government of Mexico (in Spanish), August 2022, see https://www.gob.mx/cms/uploads/attachment/file/754392/Reporte_Anual_Pot__Mit_SE__VF.pdf, accessed 5 July 2023.

1965 - SENER, "La política energética requería un cambio radical; hoy lo hizo el presidente López Obrador", Secretaría de Energía/Ministry of Energy, Government of Mexico (in Spanish), 18 March 2023, see http://www.gob.mx/sener/es/articulos/la-politica-energetica-requeria-un-cambio-radical-como-hace-85-anos-con-el-general-cardenas-hoy-lo-hizo-el-presidente-lopez-obrador-329569?idiom=es, accessed 28 June 2023.

1966 - Amy Stillman, "Mexico Blocks European Solar and Wind Plants to Favor State Utility", *Bloomberg*, 13 July 2022, see https://www.bloomberg.com/news/articles/2022-07-13/engie-enel-and-acciona-wind-solar-plants-blocked-in-mexico, accessed 13 July 2022.

1967 - Jason Deign, "Industry Stunned as Mexico Cancels Clean Power Auction", *GreenTech Media*, 4 February 2019, see https://www.greentechmedia.com/articles/read/industry-stunned-as-mexico-cancels-clean-power-auction, accessed 3 July 2023.

1968 - Oscar Lopez, "Mexico Sees Its Energy Future in Fossil Fuels, Not Renewables", *The New York Times*, 17 August 2022, see https://www.nytimes.com/2022/08/17/world/americas/mexico-president-renewable-energy.html, accessed 6 July 2023.

In 2022, Mexico recorded its highest emission rate of carbon dioxide from energy of the decade.[1969] The country's total electricity generation (gross) rose by 10.7 TWh in 2022—to reach 340.7 TWh—while nuclear and non-hydro renewables' production dropped by 1.1 TWh respectively. The increase in electricity generation and drop in both nuclear and non-hydro renewables production were covered by a dramatic rise in fossil fuel generation—+8.3 TWh for coal (a 61.4 percent increase), +2.3 TWh for natural gas and +1.3 TWh for oil—and a slight uptick of 0.8 TWh in hydro. Thus, nuclear generation remained far behind natural gas (191.8 TWh), non-hydro renewables (46.2 TWh), hydro (35.7 TWh), oil (34.2 TWh) and coal (21.9 TWh).[1970] According to SENER, both wind and solar PV represented 6 percent individually.[1971]

Installed wind capacity grew by 158 MW in 2022 to reach a total of 7.3 GW, while solar PV increased by 855 MW to amount to a total of 9 GW. Virtually the entire solar capacity was deployed in the past decade, as it only totaled 0.2 MW in 2012.[1972]

The present government's policies have slowed-down the deployment of renewables. However, President López Obrador's most controversial energy reform[1973]—which could have "derail[ed] more than [US]$22 billion of solar, wind and other renewable-energy installations owned by major foreign companies" or 15 GW of clean-energy installations, according to *Bloomberg*[1974] failed in 2022. Intense lobbying from the U.S. seems to have also contributed to some concessions on the involvement of foreign companies in the Mexican energy sector and the role of renewables.[1975]

Mexico and the U.S. held a joint press conference at COP27 further detailing their cooperation on "Plan Sonora", which is to be a "clean energy powerhouse" near the U.S. border, with renewables (including five solar plants), lithium mining, and manufacturing of electric vehicles. On that occasion, Mexico also revealed its updated NDC and intention to add 30 GW of wind, solar, geothermal and hydroelectric capacity to the grid by 2030 through the investment of about US$48 billion (from the public and private sector).[1976] In February 2023, the first stage

1969 - Energy Institute, KPMG and Kearney, "Statistical Review of World Energy 2023", 72nd Edition, June 2023, see https://knowledge.energyinst.org/search/record?id=138106, accessed 3 November 2023.

1970 - Ibidem.

1971 - SENER, "Programa de Desarrollo del Sistema Eléctrico Nacional 2023-2037", May 2023, op. cit., Figure 4.9.

1972 - Energy Institute, KPMG and Kearney, "Statistical Review of World Energy 2023", 72nd Edition, June 2023, see https://www.energyinst.org/__data/assets/pdf_file/0004/1055542/EI_Stat_Review_PDF_single-2.pdf, accessed 29 June 2023.

1973 - Fitch Wire, "Regulatory Uncertainty Persists with Mexican Energy Reform Rejection", Fitch Ratings, 21 April 2022, see https://www.fitchratings.com/research/infrastructure-project-finance/regulatory-uncertainty-persists-with-mexican-energy-reform-rejection-21-04-2022; and Drazen Jorgic and Dave Graham, "Mexican president's contentious electricity overhaul defeated in Congress", *Reuters*, 18 April 2022, see https://www.reuters.com/world/americas/mexican-lawmakers-vote-presidents-contentious-electricity-overhaul-2022-04-17/, both accessed 5 July 2023.

1974 - Amy Stillman, "Mexico Bill Puts $22 Billion in Clean Energy Contracts at Risk", *Bloomberg*, 17 November 2021, see https://www.bloomberg.com/news/articles/2021-11-17/mexico-s-amlo-puts-22-billion-in-energy-contracts-at-risk?, accessed 29 June 2023.

1975 - President Andrés Manuel López Obrador, "Discurso del presidente Andrés Manuel López Obrador en el Foro de las Principales Economías sobre Energía y Acción Climática", Government of Mexico (in Spanish), 17 June 2022, see http://www.gob.mx/sre/documentos/discurso-del-presidente-andres-manuel-lopez-obrador-en-el-foro-de-las-principales-economias-sobre-energia-y-accion-climatica?idiom=es, accessed 3 July 2023.

1976 - United Nations, "Mexico's Climate Commitments", Press Conference, 12 November 2022, see https://unfccc.int/event/mexico-s-climate-commitments, accessed 3 July 2023; and Government of Mexico, "Mexico announces new commitments to combat climate change at COP27", Press Release, 14 November 2022, see https://www.gob.mx/sre/prensa/mexico-announces-new-commitments-to-combat-climate-change-at-cop27, accessed 5 July 2023.

of the Puerto Peñasco solar plant in Sonora was inaugurated. Once fully operational the plant will add 1 GW of solar and 192 MW in battery storage.[1977]

While nearshoring investments are booming in Mexico in the spirit of "renationalization", a US$6 billion-deal saw over 77 percent of Iberdrola's installed capacity in Mexico sold to a state-owned fund in April 2023. As a result of this transaction, CFE now holds over half of the power generation market. The event was summed-up at Fitch Solutions as "Iberdrola was bullied out of the sector and that will discourage future development."[1978]

In November 2022, a nuclear cooperation agreement with the U.S.—signed in 2018 and ratified in March 2022—came into force,[1979] followed by the issuance in late December 2022 of a "Determination" from the U.S. Department of Energy to expand "Mexico's generally authorized destination status to cover the full scope of exports of controlled nuclear technology and assistance."[1980] This expansion—effective as of February 2023—lifts the restriction of nuclear-related information and assistance U.S. entities are allowed to provide to Mexico, which was previously limited to Laguna Verde or research facilities.

In late July 2023, President López Obrador, during a press conference, cut potential misunderstandings short:

> I believe that in order to avoid speculation it would be good to state clearly: we are not going to promote the creation of nuclear plants.[1981]

Mexico will see a presidential election in 2024, which will likely determine the future of the country's energy and climate change policies. Claudia Sheinbaum, candidate of the ruling Morena party, is leading in the polls. The former mayor of Mexico City is a trained physicist and was a co-author of the IPCC's Fourth and Fifth Assessment Reports as an energy efficiency expert. She did her PhD work at the Lawrence Berkley National Laboratory in California, among the world's most renowned research, development, and educational hub on energy efficiency.[1982]

1977 - CFE, "Más Energía Limpia de CFE Para México; Entra en Operación la Primera Etapa de la Central Fotovoltaica Puerto Peñasco", Press Release (in Spanish), 17 February 2023, see https://app.cfe.mx/Aplicaciones/OTROS/Boletines/boletin?i=3788, accessed 6 July 2023.

1978 - Rebecca Conan, "Sonora Plan to boost Mexico nearshoring: Fitch", *Argus*, 12 April 2023, see https://www.argusmedia.com/en//news/2438614-sonora-plan-to-boost-mexico-nearshoring-fitch; also Barney Jopson, Michael Stott and Christine Murray, "Mexico hails 'new nationalisation' as Iberdrola sells $6bn of power assets and pivots to US", *Financial Times*, 5 April 2023, see https://www.ft.com/content/c239c211-a327-4eb7-bedf-95ce81c2bd96, accessed 3 July 2023.

1979 - U.S. Department of State, "U.S.-Mexico Civil Nuclear Cooperation Agreement Enters into Force", Press Release, 3 November 2022, see https://www.state.gov/u-s-mexico-civil-nuclear-cooperation-agreement-enters-into-force/; and Brendan O'Boyle, "U.S.-Mexico nuclear cooperation agreement enters into force", *Reuters*, see https://www.reuters.com/world/americas/us-mexico-nuclear-cooperation-agreement-enters-into-force-2022-11-03/; both accessed 5 July 2023.

1980 - U.S.DOE, "Assistance to Foreign Atomic Energy Activities; Secretarial Determination—Notice", U.S. Department of Energy, United States Government, as published in the Federal Register, Vol. 88, No.20, 31 January 2023, see https://www.govinfo.gov/content/pkg/FR-2023-01-31/pdf/2023-01960.pdf; and William Freebairn, "US DOE changes rules for nuclear information exchange with Mexico, Colombia, Egypt", S&P Global, 10 February 2023, see https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/021023-us-doe-changes-rules-for-nuclear-information-exchange-with-mexico-colombia-egypt, both accessed 5 July 2023.

1981 - César Huerta, "AMLO descarta planes para construir más centrales nucleares en México: 'La que tenemos está funcionando muy bien'", *infobae*, 31 July 2023, see https://www.infobae.com/mexico/2023/07/31/amlo-descarta-planes-para-construir-mas-centrales-nucleares-en-mexico-la-que-tenemos-esta-funcionando-muy-bien/, accessed 25 August 2023.

1982 - Energy Technologies Area, "Mexico City Mayor-Elect Claudia Sheinbaum Visits Berkeley Lab", Berkeley Lab, Lawrence Berkeley National Laboratory, 9 November 2018, see https://eta.lbl.gov/news/mexico-city-mayor-elect-claudia, accessed 23 October 2023.

United States

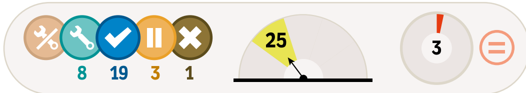
See Focus Countries – United States Focus.

ASIA

China

See Focus Countries – China Focus.

India



India has 19 operational nuclear power reactors, with a total net generating capacity of 6.3 GW. Even though the Rajasthan-1 reactor figures in the "Plants Under Operation" list on the Nuclear Power Corporation of India (NPCIL) website, it has not generated power since 2004 and is considered permanently closed. Three units fall under the LTO category: Tarapur-1 (TAPS-1), Tarapur-2 (TAPS-2), and Madras-1 (MAPS-1). Madras-1 has not generated any electricity since 2019, and both Tarapur-1 and -2 since 2021. According to the Department of Atomic Energy, RAPS-1 "is under extended shutdown for techno-economic assessment" and "TAPS-1&2 & MAPS-1 are presently under project mode."[1983] India's Nuclear Power Corporation uses the term "project mode" to describe reactors that are temporarily shut down, for example when they are undergoing replacement of coolant channels.[1984]

The list of operating reactors includes Kakrapar-3, which was first connected to the grid in January 2021, but was declared commercially operating only in June 2023.[1985] When the reactor was first connected to the grid, the chairman of NPCIL wrote to India's Ministry of Power that the reactor would produce at full capacity only by October/November 2022 because "design validation was in progress" and due to "safety issues".[1986] The Ministry advised NPCIL "to expeditiously complete the commissioning while keeping into account all the safety considerations".[1987]

Without including Kakrapar-3—operational data has not been released—the fleet of operating reactors in India generated 42 TWh in 2022 which constituted 3.1 percent of all the grid-fed electricity in the country. Nuclear electricity generation was slightly higher than in 2021, when these reactors put out 40 TWh, but the share is marginally lower than the 3.2 percent in 2021.

1983 - Lok Sabha, "Unstarred Question No. 143: Nuclear plants in the country", Parliament Question & Answers, Lok Sabha Winter Session 2022, Department of Atomic Energy, answered by Jitendra Singh, Minister of State for personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, December 2022, see https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2023/02/2023020793.pdf, accessed 30 July 2023.

1984 - NPCIL, "32nd Annual Report 2018-19", Nuclear Power Corporation of India Limited, September 2019, see https://www.npcil.nic.in/WriteReadData/userfiles/file/NPCIL_Annual_Report_2018_19_English_16dec2019.pdf, accessed 23 August 2023.

1985 - *PTI*, "India's first domestically built 700 MW nuclear reactor starts commercial operations in Gujarat", *The Economic Times*, 30 June 2023, see https://economictimes.indiatimes.com/industry/energy/power/indias-first-domestically-built-700-mw-nuclear-reactor-starts-commercial-operations-in-gujarat/articleshow/101401165.cms?from=mdr, accessed 2 July 2023.

1986 - Sudarshan Varadhan and *Reuters*, "Operation of Fourth Nuclear Power Unit in Gujarat's Kakrapar Delayed", *The Wire*, 1 June 2022, see https://thewire.in/energy/operation-of-fourth-nuclear-power-unit-in-gujarats-kakrapar-delayed, accessed 2 June 2022.

1987 - Ibidem.

However, the Energy Institute reports that nuclear reactors generated 46.2 TWh (gross), but it also estimates that nuclear power's share of all electricity produced is only 2.5 percent.[1988]

Delays in Construction and Plans

India is building eight more reactors with a combined capacity of 6.0 GW. The oldest of these is the Prototype Fast Breeder Reactor (PFBR) that has been under construction since October 2004. Next are three Pressurized Heavy Water Reactors (PHWRs), starting with Kakrapar-4 (under construction since November 2010) and Rajasthan-7 and -8 (since July and September 2011). Finally, there are four VVER-1000s at Kudankulam, whose construction started in June and October 2017 for the first two units, and June and December 2021 for the second pair.

Most, possibly all, of these are delayed. The PFBR is now scheduled to be commissioned in December 2024, over 20 years after construction start and over 14 years past the initially projected commissioning date of September 2010.[1989] Kakrapar-4 is now scheduled to be commissioned in March 2024, over eight years after the projected December 2015. The two reactors in Rajasthan are now due to be completed in 2026, around ten years after the original date of December 2016.[1990] A media report from August 2022 announced that Larsen & Toubro, a prominent engineering firm, had received an order "to build natural draught cooling towers and a cooling water pump house for the Rawatbhata atomic power project 7 and 8" and the "project is scheduled to be completed in 36 months".[1991] The VVER reactors being imported from Russia are less delayed. According to a government statement in parliament in April 2023, the anticipated date of commissioning for Kudankulam-3 and -4 is 2025, nearly five years after the original scheduled startup date of November 2020.[1992] Only Kudankulam-5 and -6 are still scheduled to be commissioned in 2027, although that might well change in the future.

Alongside these delays, the estimated costs of these reactors have also gone up.[1993] The PFBR's cost has more than doubled from the initially anticipated Rs.34.9 billion to Rs.77 billion as of May 2023.[1994] The Kakrapar project, where Unit 3 has already been commissioned, has already resulted in the expenditure of Rs.202.6 billion, up from Rs.114.6 billion; the Rajasthan project is now expected to cost Rs.170.8 billion, up from Rs.123.2 billion. Kudankulam-3 and -4 are still projected to cost Rs.398.5 billion but that is likely to go up.

1988 - Energy Institute, "Statistical Review of World Energy 2023—Data", June 2023, op. cit.

1989 - MoSPI, "450th Flash Report on Central Sector Projects (Rs. 150 crore and above)", Ministry of Statistics and Programme Implementation, Government of India, May 2023, see http://www.cspm.gov.in/english/flr/FR_May_2023.pdf, accessed 28 June 2023.

1990 - Rajya Sabha, "Unstarred Question No. 3842: Status of new nuclear power plants", Department of Atomic Energy, answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 6 April 2023, see https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2023/04/2023041254.pdf, accessed 28 June 2023.

1991 - *Swarajya*, "L&T Construction Arm To Build Natural Draught Cooling Towers For Rawatbhata Atomic Power Project In Rajasthan", 10 August 2022, see https://swarajyamag.com/business/lt-construction-arm-to-build-natural-draught-cooling-towers-for-rawatbhata-atomic-power-project-in-rajasthan, accessed 23 August 2023.

1992 - Ibidem.

1993 - MoSPI, "450th Flash Report on Central Sector Projects (Rs. 150 crore and above)", Government of India, May 2023, op. cit.

1994 - As of August 2023, the conversion rate to US dollars is around Rs. 82 per US dollar. However, the PFBR costs are in mixed-year Rupees and so directly converting it into other currencies using one conversion rate is misleading.

As discussed in detail in WNISR2022, plans for building a large number of PHWRs have been announced by the Indian government for many years now, and have been continuously pushed back. There has been no first pour of concrete for any of these new reactor projects so far. The first of these are likely to be in Gorakhpur in Haryana state (GHAVP-1&2). In December 2022, the government announced that GHAVP-1 and -2's "foundation piles" are completed "and testing is underway" and "construction of other buildings and structures is underway".[1995]

There is no concrete progress with India's plans to import reactors from the U.S. and France which has been talked about ever since the U.S.-India nuclear deal was negotiated between 2005 and 2008.[1996] As discussed in WNISR2022, one reason for the reluctance of U.S. vendors to enter into any agreements has been their refusal to accept any liability for accidents.[1997] France's EDF continues to be interested in building six EPRs at the Jaitapur site, but there continues to be disagreement over the EDF offer, including over liability for accidents.[1998] Nevertheless, political leaders continue to emphasize "their commitment to the success of the Jaitapur EPR project".[1999]

Power Mix and Current Policies

While nuclear power remains mired in delays, renewable energy has been progressing rapidly. According to the International Renewable Energy Agency (IRENA), total renewable energy capacity grew by a factor of 2.5 from 63.6 GW in 2013 to 163 GW in 2022.[2000] In 2022 alone, installed capacity grew by 10 percent. Most of this annual growth is in solar energy, which went up by 27 percent to an installed capacity of 63.2 GW, over ten times the installed capacity of nuclear reactors. Wind energy capacity reached 41.9 GW, an increase of 4.6 percent compared to 2021.

The Energy Institute reports the combined output of renewables in India as 205.9 TWh gross—up 18.9 percent from 173.2 TWh in 2021—representing 11 percent of all the electrical energy.[2001] Of this, wind energy contributed 70 TWh (69.3 TWh net) and solar energy 95.2 TWh (94.2 TWh net). In other words, wind and solar power generated individually 1.5 times more than nuclear power, with solar power alone contributing more than twice what nuclear reactors generated.

1995 - Lok Sabha, "Unstarred Question No. 1179: Setting up of New Nuclear Plants", Parliament Question & Answers Lok Sabha, Winter Session 2022, Department of Atomic Energy, answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 14 December 2022, see https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2023/02/2023020798.pdf, accessed 30 July 2023.

1996 - Prerna Gupta and M. V. Ramana, "A Decade After the Nuclear Deal", *The India Forum*, 3 April 2019, see https://www.theindiaforum.in/article/decade-after-nuclear-deal, accessed 17 May 2020.

1997 - M. V. Ramana and Suvrat Raju, "The Impasse Over Liability Clause in Indo-U.S. Nuclear Deal", *India Ink*, 15 October 2013, see http://india.blogs.nytimes.com/2013/10/15/the-impasse-over-liability-clause-in-indo-u-s-nuclear-deal/?_r=0; and M. V. Ramana and Suvrat Raju, "Profitability without accountability", *The Hindu*, 16 February 2015, see http://www.thehindu.com/opinion/op-ed/comment-profitability-without-accountability/article6898851.ece; both accessed 29 September 2023.

1998 - Suhasini Haidar, "Nuclear liability issues not yet resolved for Jaitapur project: French company EDF", *The Hindu*, 24 April 2023, see https://www.thehindu.com/news/national/nuclear-liability-issues-not-yet-resolved-for-jaitapur-project-french-company-edf/article66774668.ece, accessed 23 August 2023.

1999 - Huma Siddiqui, "France and India collaborate on Jaitapur Power Plant and Advanced Nuclear Reactors", *FinancialExpress*, 17 July 2023, see https://www.financialexpress.com/business/defence-france-and-india-collaborate-on-jaitapur-power-plant-and-advanced-nuclear-reactors-3173916/, accessed 23 August 2023.

2000 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

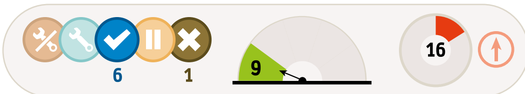
2001 - Energy Institute, "Statistical Review of World Energy 2023—Data", June 2023, op. cit.

Looking to the future, the National Electricity Plan released by the Central Electricity Authority of the Ministry of Power in May 2023 foresees nuclear capacity expanding by 6.3 GW between 2022 and 2027 in four of its five scenarios, whereas solar energy is projected to expand by 92.6 GW and wind by 25 GW in the same four scenarios.[2002] The report also stated that newly installed nuclear capacity between 2017 and 2022 was 0 kW, instead of the anticipated 3.3 GW. Solar and wind capacity installed during the same period were 41.7 GW and 80.8 GW. Even Biomass & Waste to Energy projects and small hydro, with 2.4 GW and 4.7 GW, exceeded nuclear installations. In other words, even India's energy planners don't expect nuclear power to contribute much to the growth of the power sector whereas renewables are expected to continue expanding rapidly. These are in line with the Indian government's stated aim to add 500 GW of renewables by 2030.[2003]

Japan

See Focus Countries – Japan Focus.

Pakistan



Pakistan operates six nuclear reactors with a combined (net) capacity of 3.3 GW. This includes Unit 3 of the Karachi Nuclear Power Station (Kanupp) that was connected to the grid on 4 March 2022, started operating commercially in April 2022 but was formally inaugurated by Pakistan's Prime Minister Shehbaz Sharif only in February 2023,[2004] and received an operating license from the Pakistan Nuclear Regulatory Authority only in May 2023.[2005]

Nuclear electricity production in Pakistan has increased from 15.8 TWh in 2021 to 22.2 TWh in 2022. The share of electricity from nuclear power plants increased from 11.5 percent in 2021 to 16.2 percent in 2022.

Kanupp-3 and its sister unit, Kanupp-2, were the first Hualong One reactors built by the China National Nuclear Corporation (CNNC) outside China. Pakistan had earlier imported the four operating CNP-300 nuclear reactors in Chashma from CNNC.[2006]

In June 2023, the two countries signed an agreement to build a Hualong One reactor at Chasma; the deal for Chashma-5 is said to be for US$4.8 billion, and Pakistan's Prime Minister announced

2002 - CEA, "National Electricity Plan—Volume I—Generation", Central Electricity Authority, Ministry of Power, Government of India, May 2023, see https://cea.nic.in/wp-content/uploads/notification/2023/06/NEP_2022_32_FINAL_GAZETTE_English.pdf, accessed 28 June 2023.

2003 - Michael Lustig and Anna Duquiatan, "India aims to add 500 GW of renewables by 2030", S&P Global, 5 July 2022, see https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/india-aims-to-add-500-gw-of-renewables-by-2030-70713616, accessed 8 July 2022.

2004 - *NEI Magazine*, "Pakistan launches unit 3 at Karachi NPP", *Nuclear Engineering International*, 8 February 2023, see https://www.neimagazine.com/news/newspakistan-launches-unit-3-at-karachi-npp-10577061, accessed 12 February 2023.

2005 - PNRA, "Award of Operating License (OL) to Karachi Nuclear Power Plant Unit-3 (K-3)", Pakistan Nuclear Regulatory Authority, 31 May 2023, see https://www.pnra.org/K3-ol.html, accessed 6 June 2023.

2006 - CNNC, "Chinese overseas nuclear power unit passes final acceptance", China National Nuclear Corporation, 10 December 2019, see https://en.cnnc.com.cn/2019-12/10/c_446316.htm, accessed 8 May 2022.

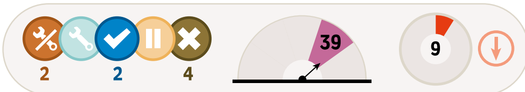
on the state-run news channel that work on the project would "begin immediately".[2007] The project has been formally underway since 2017 when CNNC and the Pakistan Atomic Energy Commission (PAEC) signed a cooperation agreement.[2008] The high cost of the reactor will add to the already major financial problems and challenges with repaying loans that Pakistan is facing.[2009]

Pakistan's renewable energy capacity continues to grow, reaching a total of 13.9 GW in 2022, an 8 percent increase compared to 2021, and 84 percent more than the 2013 capacity of 7.6 GW.[2010] The most important component of this capacity is hydropower, with 10.8 GW, it accounts for approximately 78 percent of total installed renewable energy capacity. The total capacities of wind and solar, 1.4 GW and 1.2 GW respectively, are up by 7.5 percent and 15 percent, when compared to 2021.

South Korea

See Focus Countries – South Korea Focus.

Taiwan



Taiwan has two operating reactors at Maanshan, owned by the Taiwan Power Company (Taipower), the state-owned utility monopoly. The latest reactor to close was the 985-MW BWR Kuosheng-2 (or Guosheng), on 14 March 2023[2011], following the closure of Kuosheng-1 in July 2021. In 2022, nuclear generation dropped again, by 14.5 percent to 22.9 TWh, contributing 9.1 percent to the country's electricity production. This is the lowest nuclear share in the power mix since 1978. Nuclear generation reached its maximum contribution of 41 percent in 1988.[2012]

Due to the January 2020 re-election of President Tsai Ing-wen of the Democratic Progressive Party (DPP), the nuclear-phaseout and energy-transition policy enacted in the first term, remains the official strategy.[2013]

2007 - *Reuters*, "China and Pakistan sign $4.8 billion nuclear power plant deal", as published by *CNN*, 21 June 2023, see https://www.cnn.com/2023/06/20/asia/pakistan-china-nuclear-power-plant-deal-intl-hnk/index.html, accessed 25 June 2023.

2008 - *WNN*, "Pakistan, China agree to build Chashma 5", *World Nuclear News*, 23 November 2017, see https://www.world-nuclear-news.org/Articles/Pakistan,-China-agree-to-build-Chashma-5, accessed 8 May 2022.

2009 - *The News*, "China rescued Pakistan amid delay in IMF deal: PM Shehbaz", 20 June 2023, see https://www.thenews.com.pk/latest/1082620-china-rescued-pakistan-amid-delay-in-imf-deal-pm-shehbaz, accessed 30 June 2023; and Mushtaq Ghumman, "N-power plants set up by China face financial problems", *Business Recorder*, 13 April 2022, see https://www.brecorder.com/news/40166993/n-power-plants-set-up-by-china-face-financial-problems, accessed 8 May 2022.

2010 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

2011 - Taipower, "Kuosheng Nuclear Power Plant Unit No. 2 Decommissioned in Accordance with the Law Annual Maintenance Has Been Scheduled, and New Units Will Take Over in the Summer for Flexible Dispatch and Stable Pow", Press Release, Taiwan Power Company, 13 March 2023, see https://www.taipower.com.tw/en/news_info.aspx?id=143&chk=ea31a318-ee2c-4d1b-8ffd-b2d3efed4873&mid=4412, accessed 24 July 2023.

2012 - Taipower, "Nuclear Power Status and Performance - Power Generation Information", Taiwan Power Company, 2022, see https://www.taipower.com.tw/EN/page.aspx?mid=4494&cid=2922&cchk=1ea334fb-c4f5-42d4-bfd6-93fecb80e250, accessed 23 September 2023; and IAEA-PRIS statistics.

2013 - Yang Chun-hui, Shih Hsiao-kuang and Lin Liang-sheng, "2020 Elections: Tsai wins by a landslide", *Taipei Times*, 12 January 2020, see https://www.taipeitimes.com/News/front/archives/2020/01/12/2003729107, accessed 7 July 2021.

During the previous term, citizens voted in a 2018-referendum to remove the amendment to the Electricity Act which made the 2025-phaseout deadline legally binding. The paragraph was withdrawn, but the government's commitment to the policy remains intact, thus Kuosheng-2 was the fourth Taiwanese reactor to be closed under the current government's nuclear phaseout plan and another milestone in the island's energy transition.

Taipower stated that wind power was providing "in winter often more than 1 GW" and that with more than 1.3 GW of additional thermal capacity coming online they would exceed the closed capacity of Kuosheng-2. The utility also noted in March 2023 that "at present, the solar power generation capacity is often more than 5 GW during the daytime and can relieve pressure on the power supply during daytime hours, whereas the hydropower can also be reserved for use at night."[2014]

The opposition Chinese Nationalist Party (KMT) continues to reject President Tsai's energy policy, calling for a life extension of existing reactors and the construction of new plants, and points to renewed international interest in nuclear power and to the technology's inclusion in the E.U.'s sustainability taxonomy.[2015] Reportedly, "some KMT politicians have even mooted the idea of deploying small modular reactors (SMRs) if the party regains power."[2016]

Hou Yu-ih, the current mayor of New Taipei City and KMT's candidate for the January 2024 presidential elections, outlined his energy policy plans in a press conference in August 2023. Reportedly, significantly deviating from earlier positions,[2017] he "promised that if elected, he would ensure examinations and repairs of the first three nuclear power plants in the country [two of which are already closed] and establish a safety review committee to re-examine the decision to discontinue construction of the fourth plant during his term in office".[2018]

Recent opinion surveys have consistently shown the governing DPP candidate William Lai leading the polls, with mayor Hou falling back to third place behind the Taiwan People's Party (TPP) candidate, Ko Wen-je.[2019]

Environmental organization Green Citizen Action Alliance stated:

> Green Citizen Action Alliance argues that nuclear power is too slow and too expensive to be a feasible solution at this critical moment in Taiwan when facing the climate crisis and the urgent need for energy transition, and it shouldn't be a political stunt during each election to distract people from the real debate and the way towards energy transition.[2020]

2014 - Taipower, "Kuosheng Nuclear Power Plant Unit No. 2 Decommissioned in Accordance with the Law Annual Maintenance Has Been Scheduled, and New Units Will Take Over in the Summer for Flexible Dispatch and Stable Pow", 13 March 2023, op. cit.

2015 - Liu Kuan-ting, Wen Kuei-hsiang, Hsieh Fang-we and Shih Hsiu-chuan, "KMT's Ma, DPP butt heads over nuclear phase-out", *Focus Taiwan*, 16 July 2022, see https://focustaiwan.tw/business/202207160020; and Shih Hsiao-kuang and Jake Chung, "KMT calls for extensions of nuclear power licenses", *Taipei Times*, 23 April 2022, see https://www.taipeitimes.com/News/taiwan/archives/2022/04/23/2003777091; both accessed 1 September 2022.

2016 - Dennis Engbarth, "Taiwan: Debating the Phaseout as Kuosheng-2 is Retired", *Nuclear Intelligence Weekly*, 17 March 2023.

2017 - The WNISR-Coordinator met with Hou Yu-ih, then incoming mayor of New Taipei City, in 2018.

2018 - *Focus Taiwan*, "KMT presidential candidate to restart nuclear power plants if elected", *CNA English News*, 9 August 2023, see https://focustaiwan.tw/politics/202308090024, accessed 24 September 2023.

2019 - *Taipei Times*, "Ko overtakes Hou in presidential favorability", 21 June 2023, see https://www.taipeitimes.com/News/taiwan/archives/2023/06/21/2003801902, accessed 25 September 2023.

2020 - Personal communication by email, 28 September 2023.

Pro-nuclear lobbying had experienced a major setback in December 2021, when a referendum rejected a proposal to resume construction of two reactors at the Lungmen Nuclear Power Plant.[2021] The vote was significant as it showed the population's support for current government policy but, whatever the outcome, it would have remained rather symbolic as in view of the dire state of the Lungmen project, it is unlikely that a favorable outcome would have translated into policy changes or any concrete action leading to operation of the plant (see The Lungmen Saga.)

As part of an ongoing reform, the government announced in May 2022 that it was working on replacing the current regulator, the Atomic Energy Commission (AEC), with an independent nuclear regulator, the Nuclear Safety Commission. The new commission would be tasked to oversee and implement waste management, which will be a major challenge in the coming decades due to the scheduled closure of the remaining nuclear fleet by 2025 and ensuing decommissioning activities.[2022] The authority was to be set up about a decade ago,[2023] and an organizational act was passed in early 2013 as part of restructuring ministerial affiliations[2024], yet, as of July 2023, the AEC was still exercising regulatory oversight in Taiwan. No information about potential developments has been published in the past year.

Reactor Closures

As reported in previous editions, Taipower announced the closure of Chinshan-1 on 5 December 2018, while Chinshan-2 has remained shut down from June 2017 but was officially closed on 15 July 2019, when its 40-year operating license expired.

On 1 July 2021, Taipower announced that due to a lack of spent fuel storage capacity, Kuosheng-1 had been closed six months ahead of schedule.[2025] The closure of Kuosheng-1, located on the northern coast only 22 km northeast of Taipei City, was originally planned for 27 December 2021 when its operating license expired. A new batch of nuclear fuel had been loaded into the reactor during the refueling and maintenance outage in 2020 but in February 2021, Taipower reduced the reactor power-level to 80 percent to save fuel and allow it to extend operations until the higher-consumption month of June.[2026]

Kuosheng-2, closed in March 2023 as previously mentioned, was a 985 MW BWR/6 unit supplied by General Electric (GE) and was connected to the grid on 29 June 1982.

2021 - Ben Blanchard, "Taiwan referendums fail in major setback for opposition", *Reuters*, 18 December 2021, see https://www.reuters.com/markets/commodities/taiwan-opposition-hopes-boost-contentious-referendums-2021-12-18/, accessed 4 September 2022.

2022 - Matthew Strong, "Taiwan plans to set up independent nuclear safety commission", *Taiwan News*, 4 May 2022, see https://www.taiwannews.com.tw/en/news/4527845, accessed 1 September 2022.

2023 - WNA, "Nuclear Power in Taiwan", World Nuclear Association, Updated July 2022, see https://world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx, accessed 1 September 2022.

2024 - Executive Yuan, "Nuclear Safety Commission organizational act passed by the Executive Yuan", Press Release, Government of Taiwan, 21 February 2013, see https://english.ey.gov.tw/Page/61BF20C3E89B856/90b39fbf-96d0-428f-9c60-0f9a0f7c81cf, accessed 1 September 2022.

2025 - Taipower, "核二1號機燃料池滿今提前停機 台電: 歲修機組陸續歸隊與民營電廠機組加入，持續確保供電無虞" ["NPP No. 2's Fuel Pool is Full and Shut Down Early Today TEPCO: Year-end Repair Teams Returning and Private Power Plant Teams Joining to Ensure Continuous Supply of Electricity"], 1 July 2021, see https://www.taipower.com.tw/tc/news_info.aspx?id=4741&chk=75ddf691-44f7-406a-922c-ebf676c2fbd8&mid=17, accessed 27 September 2023.

2026 - *WNN*, "Early shutdown for Taiwanese reactor", *World Nuclear News*, 1 July 2021, see https://www.world-nuclear-news.org/Articles/Early-shutdown-for-Taiwanese-reactor, accessed 7 July 2021.

Maanshan's two PWRs are scheduled for closure on 26 July 2024 and 17 May 2025 respectively. In line with the official policy and current regulation, the application for the closure of the Maanshan plant was submitted in July 2021.[2027]

The Lungmen Saga

A referendum was held in December 2021 that included a proposal to overturn the current nuclear phaseout policy, by asking voters to approve the construction restart of two ABWRs at the Lungmen Nuclear Power Plant. The vote resulted in the rejection of the proposal by a 5.7 percent margin (47.2 percent in favor, 52.8 percent against).[2028]

Construction at the two units started in 1999. According to the AEC, as of the end of March 2014, Lungmen-1 was 97.7 percent complete,[2029] while Lungmen-2 was 91 percent complete. The plant was by then estimated to have cost NT$300 billion (US$$_{2014}$9.9 billion).[2030] After multiple delays, rising costs, and large-scale public and political opposition, including through local referendums, on 28 April 2014, then Premier Jiang Yi-huah announced that Lungmen-1 will be mothballed after the completion of safety checks while work on Unit 2 at the site was also to be stopped. In December 2014, it was announced that the project was put on hold for three years.[2031] It never resumed.

There was little prospect that the units would ever operate even with a different referendum outcome, considering that resumption would have required Taiwan's legislature and AEC approval, which was not going to happen given the current government was reelected with the promise to end nuclear power generation by 2025. Taipower has long considered a completion of the project "neither feasible nor desirable."[2032]

Beyond industrial or political will, a plethora of obstacles compromised the realism of resuming construction. First, new licensing processes and a new environmental impact assessment would have been necessary as the initial construction permit expired at the end of 2020. This would have required additional geological surveys since a seismic fault running two kilometers beneath both reactors was identified in 2014.[2033]

Even if the seismic fault was proven inactive, numerous further technical challenges would still have to be overcome. Taipower explained in February 2019 that it would not be able to simply replace major components installed nearly 20 years ago, including instrumentation and

2027 - *NEI Magazine*, "Taipower applies to close down Maanshan NPP", *Nuclear Engineering International*, 29 July 2021, see https://www.neimagazine.com/news/newstaipower-applies-to-close-down-maanshan-npp-8946136/, accessed 1 September 2022.

2028 - Brian Hioe, "DPP Sweeps Taiwan's Latest Referendum Vote", *The Diplomat*, see https://thediplomat.com/2021/12/dpp-sweeps-taiwans-latest-referendum-vote/, accessed 1 September 2022.

2029 - Planning Department, "Status and Challenges of Nuclear Power in Taiwan", AEC, April 2014, see http://www.aec.gov.tw/english/whatsnew/files/20140506-5.pdf, accessed 7 July 2021.

2030 - *WNN*, "Political discord places Lungmen on hold", *World Nuclear News*, 28 April 2014, see http://www.world-nuclear-news.org/NN-Political-discord-places-Lungmen-on-hold-2804144.html, accessed 7 July 2021; Dennis Engbarth, "Technology: Investigation Belies GEH Claims About ABWRs", *NIW*, 19 November 2021.

2031 - Clara Tan, "Lungmen Put On Hold for Three Years", *NIW*, 19 December 2014; and Ministry of Foreign Affairs, "Taiwan seals Lungmen No.1 nuclear reactor", *Taiwan Today*, 1 July 2015, see https://taiwantoday.tw/news.php?unit=6&post=12347, accessed 8 September 2022.

2032 - Dennis Engbarth, "Taiwan: Tsai Pushes to Defeat Lungmen-4 Revival", *Nuclear Intelligence Weekly*, 9 April 2021.

2033 - Ibidem.

control, requiring full-scale renegotiation with the main supplier General Electric (GE).[2034] In 2021, the AEC Chairman cited a "10 years or more" timeline until grid connection of both units.[2035]

Moreover, in November 2021, the government revealed previously confidential documentation from 2015 showing the extent of unresolved safety-relevant technical issues that would impact the project should it be relaunched. The documents were unearthed during an investigation launched in summer 2019 by the government's supervisory and auditory branch, the Control Yuan, into the rationale behind two settlement payments issued by Taipower to GE. The first was a US$158 million compensation for equipment supplied at Lungmen awarded to GE by the International Chamber of Commerce (ICC). This was awarded in a December 2018 ruling (notified in March 2019), following a 3-year investigation initiated at the request of GE over cessation of payment by Taipower. A second ruling by ICC resulted in a settlement agreement between the two companies, amounting to a third of the US$66 million that GE was demanding (which Taipower said it agreed to in order to minimize compensation payment and avoid further legal fees).

Compliance with safety specifications had long been subject to contradicting assertions, including from the former-Minister of Economic Affairs, Chang Chia-chu, who declared in 2014, that Unit 1 was cleared for hot-testing based on a task-force report he commissioned. The result of this "confidence-building" exercise initiated by GE and a nuclear engineer from Bechtel (who later became a prominent critic of the project) did not involve AEC findings yet was used by the Minister to legitimize the process citing it as evidence and was still used prior to the December 2021 referendum. One of the Commissioners stated at the launch of the investigation in 2019, that sanctions could be considered either against Taipower executives or individual ministry officials, depending "on the evidence."[2036]

The probe scrutinized counterclaims filed by Taipower with the International Court of Arbitration in 2015, alleging a "wide range of system design shortcomings and noncompliance with specifications of its [GE's]… ABWR."[2037] GE was cleared at the time by blaming the suspension of the project for its shortcomings—an explanation the company has maintained. Nevertheless, documents revealed by the inquiry showed that 23 out of the 43 counterclaims remained unresolved—including some relating to emergency core cooling, and radiation monitoring—casting further doubt on costs and delay until hypothetical operation of the facility.[2038] Further findings revealed that out of 187 preoperational system-function test-reports at Lungmen-1, the AEC only approved 155, leaving 32 unresolved. Evidently, the regulator had not cleared the unit for operation. No sanctions have been announced, but the summary conclusions of the investigation state that Minister Chang's July 2014-claims had

2034 - *NEI Magazine*, "Taipower rules out operation of Lungmen", 6 February 2019, see https://www.neimagazine.com/news/newstaipower-rules-out-operation-of-lungmen-6970272, accessed 7 July 2021; and Dennis Engbarth, "Taiwan: Extending Reactor Operations 'Infeasible'", *Nuclear Intelligence Weekly*, 1 February 2019.

2035 - Dennis Engbarth, "Taiwan: Tsai Pushes to Defeat Lungmen-4 Revival", *Nuclear Intelligence Weekly*, 9 April 2021.

2036 - Dennis Engbarth, "Taiwan: GEH Awarded $158 Million in Lungmen Dispute", *Nuclear Intelligence Weekly*, 8 March 2019; and *NIW*, "Briefs—Taiwan", 23 August 2019; also Dennis Engbarth, "Taiwan: Government Probe Unearths Safety Issues With Lungmen", *Energy Intelligence*, 19 November 2021, see https://www.energyintel.com/0000017d-33fa-d08a-abfd-fffe71af0000, 4 September 2022.

2037 - Dennis Engbarth, "Taiwan: Government Probe Unearths Safety Issues With Lungmen", *Energy Intelligence*, 19 November 2021, op. cit.

2038 - Ibidem; and *NIW*, "Technology: Investigation Belies GEH Claims About ABWRs", 19 November 2021.

"no legal standing" yet "created the mistaken understanding among a part of society that the report meant that the nuclear power plant was safe."[2039]

WNISR took the units off the construction listing in 2014, where they remain as of 1 July 2023. The IAEA kept listing the Lungmen reactors as under construction at least until June 2019,[2040] however, as of 2023 they were no longer listed[2041].

Energy and Climate Policy

Historical public opposition to nuclear power in Taiwan dramatically escalated during and in the months following the Fukushima Daiichi disaster which became a principal driver of the nation's ambitious plans for a renewable energy transition. The "New Energy Policy Vision", announced by the administration in summer 2016, aims at establishing "a low carbon, sustainable, stable, high-quality and economically efficient energy system" through an energy transition and energy industry reform.[2042] On 12 January 2017, the Electricity Act Amendment completed its third reading in the legislature, setting in place Taiwan's energy transition, including the nuclear phaseout.[2043] The law also gives priority to distributed renewable energy generation by which its generators will be given preferential rates, and small generators will be exempt from having to prepare operating reserves.

President Tsai in October 2020 called for Taiwan to become a leading center of green energy in the Asia-Pacific region.2044 The island's potential for offshore wind is very high, and in 2021, the Global Wind Energy Council estimated Taiwan's offshore wind technical potential to be as high as 494 GW.[2045] Between 2021 and 2025, Taiwan aims to add 5.7 GW of offshore wind capacity to the grid. In 2020, the government's position was that an additional 10 GW of offshore wind will be added to the grid between 2026–2035.[2046] In May 2021, this was increased to 15 GW, thus corresponding to the deployment of 1.5 GW *per year* over the decade. The target has been confirmed since.[2047]

However, in the shorter term, renewable energy development had been slow until a significant boost in 2022. Combined wind and solar capacity reached 13.6 GW, over a quarter of installed capacity, and their power generation increased by 37 percent to reach 21.6 TWh and contribute

2039 - Ibidem.

2040 - IAEA-PRIS, "Taiwan, China", as of 10 June 2019, see https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=TW, accessed 11 June 2019.

2041 - IAEA-PRIS, "Taiwan, China", as of November 2023, op. cit.

2042 - MOEA, "Taiwan's New Energy Policy", 6 April 2017, Ministry of Economic Affairs, Government of Taiwan.

2043 - Bureau of Energy, "The Three-Stage Reading Process for Electricity Act Amendment Completed Moving Towards the 2025 Target of Nuclear-Free Homeland", Ministry of Economic Affairs, Government of Taiwan.

2044 - Energy Taiwan, "Energy Taiwan Establishing the Trifecta of PV Solar, Wind Power and Smart Energy Storage", 16 October 2020; and *Energy Trend*, "2020 Energy Taiwan Commenced as Taiwan Become Hot Spot for Global Green Energy Investment", 15 October 2020, see https://www.energytrend.com/news/20201015-19621.html, both accessed 7 July 2021.

2045 - GWEC, "Offshore Wind Technical Potential in Taiwan", Global Wind Energy Council, June 2021, see https://gwec.net/wp-content/uploads/2021/06/Taiwan_Offshore-Wind-Technical-Potential_GWEC-OREAC.pdf, accessed 5 September 2022.

2046 - U.S. Department of Commerce, "Taiwan Renewable Energy Market", 5 March 2021, see https://www.trade.gov/market-intelligence/taiwan-renewable-energy-market, accessed 7 July 2021.

2047 - Energy Administration, "Taiwan's Offshore Wind Market Matures, Continually Attracting International Developers", Ministry of Economic Affairs, Government of Taiwan, 10 April 2023, see https://www.moeaboe.gov.tw/ECW/english/news/News.aspx?kind=6&menu_id=958&news_id=30361, accessed 24 September 2023.

8.6 percent of the total electricity production.[2048] In December 2022, for the first time, Taiwan generated more power from wind and solar than from coal.[2049] In July 2023, solar alone injected a record 7 GW to the grid.[2050]

Current targets for 2025 place solar capacity at 20 GW and combined renewable energy capacity at 25 percent of the power mix.[2051] These goals remain ambitious, but the deployment acceleration has also been noted by investors. Taiwan moved up five places in one year and ranked 26th in Ernst & Young's Renewable Energy Country Attractiveness Index 2023.[2052]

Despite being blocked from joining the Paris Agreement and COP negotiations, the Taiwanese Government, in April 2021, unilaterally pledged to achieve Net-Zero by 2050 and announced drafting regulations to that end as well as the accelerated implementation of existing targets.[2053]

As of 2022, the island remained heavily dependent on energy imports and coal still dominated electricity generation with a 43.4 percent contribution, followed by a 34.8 percent share from natural gas.[2054] Per capita energy consumption has hardly moved over the past decade and per capita electricity consumption increased by modest 14 percent over the same period. Peak load experienced the strongest growth rate at 19.5 percent over the decade to exceed 40 GW for the first time in 2022.[2055] MOEA statistics show that in 2022, for the first time, total gross renewable energy production (including geothermal, biomass, waste, and hydro) was just above that of nuclear (90 GWh).[2056]

2048 - Taipower, "The Era of Green Energy is Coming! Taipower's General Shareholders Meeting Reviews 2022's Record-Breaking Achievements in Solar Power Generation", Taiwan Power Company, 16 June 2023, see https://www.taipower.com.tw/en/news_info.aspx?id=147&chk=ba04cede-e588-4e74-a395-d8b5d8fb2845&mid=4412, accessed 24 September 2023.

2049 - Lisa Wang, "Solar, wind power hit new milestone", *Taipei Times*, 1 March 2023, see https://www.taipeitimes.com/News/biz/archives/2023/03/01/2003795211, accessed 25 September 2023.

2050 - Taipower, "Taipower Wins 2023 Taiwan Sustainable Development Gold Award for Solar Energy Storage Achievement Showcased at WTC Exhibition Hall Come Enjoy Taipower Popsicles", Taiwan Power Company, 21 July 2023, see https://www.taipower.com.tw/en/news_info.aspx?id=150&chk=5e7d16ef-54f6-48e5-bc84-1a130e02c32b&mid=4412&param=pn%3d1%26mid%3d4412%26key%3d, accessed 24 September 2023.

2051 - Max Tingyao Lin, "Taiwan prepares regulations to meet 2050 net-zero goal despite COP26 exclusion", IHS Markit, S&P Global, 8 November 2021.

2052 - EY, "Renewable Energy Country Attractiveness Index", Ernst & Young, 59th Edition, May 2022, see https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/power-and-utilities/ey-recai-59-edition-full-report-may-2022.pdf; and EY, "Renewable Energy Country Attractiveness Index—RECAI", 60th Edition, November 2022, see https://assets.ey.com/content/dam/ey-sites/ey-com/en_us/topics/energy-resources/ey-recai-60-report-november-2022.pdf; and EY, "Renewable Energy Country Attractiveness Index", 61st Edition, June 2023, see https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/power-and-utilities/ey-recai-61-report.pdf; all accessed 27 September 2023.

2053 - Ben Blanchard, "Taiwan begins to plan for zero emissions by 2050", *Reuters*, 22 April 2022; and Office of the President, "President Tsai addresses COP26 Taiwan Day event", Government of Taiwan, 7 November 2021, see https://english.president.gov.tw/NEWS/6186; and Chang Tzi-chin, "Taiwan: Cooperating With the World to Achieve a Net-Zero Future", Environmental Protection Administration, Government of Taiwan, as published in *The Diplomat*, 28 October 2021, see https://thediplomat.com/2021/10/taiwan-cooperating-with-the-world-to-achieve-a-net-zero-future/; both accessed 6 September 2022.

2054 - Taipower, "Nuclear Power Status and Performance - Power Generation Information", Taiwan Power Company, 2022, op. cit.

2055 - Eric Chang, "Taiwan electricity use surpasses 40 GW for first time", *Taiwan News*, 21 July 2022, see https://www.taiwannews.com.tw/en/news/4602212, accessed 16 November 2023.

2056 - Bureau of Energy, "Energy Statistics Handbook 2022", Ministry of Economic Affairs, Government of Taiwan, 2023, see https://www.moeaea.gov.tw/ECW_WEBPAGE/FlipBook/2022EnergyStaHandBook/index.html#p=, accessed 16 November 2023.

The government's strategy—summarized by MOEA as "promote green energy, increase natural gas, reduce coal-fired, achieve nuclear-free"—would see natural gas consumption increase substantially, and provide 50 percent of gross electricity production by 2025.[2057]

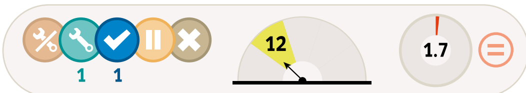
In March 2022, Taiwan's National Development Council unveiled its "Pathway to Net-Zero Emissions in 2050", an updated strategy to pursue the transition more aggressively through a wide range of measures. The strategy is based on a NT$900 billion (US$$_{2022}$32.4 billion) budget According to press reports, Deputy Minister of Economic Affairs Tseng Wen-sheng pointed out on 20 September 2023 that as Taiwan "excels at manufacturing", the future energy trend, "which no longer relies on [natural resources] but manufactured devices such as solar panels and wind turbines to get hold of power," would be a challenge but also an economic opportunity for the country.[2058]

According to press reports, Deputy Minister of Economic Affairs Tseng Wen-sheng pointed out on 20 September 2023 that as Taiwan "excels at manufacturing", the future energy trend, "which no longer relies on [natural resources] but manufactured devices such as solar panels and wind turbines to get hold of power," would be a challenge but also an economic opportunity for the country.[2059]

The reform of the electricity market is continuing with the second stage during 2019–2025 to include grid unbundling, the restructuring of Taipower into a holding company with two entities: a power generation corporation and a transmission and distribution corporation; and the separation of the accounting system for these planned within two years and complete separation within six to nine years.[2060]

MIDDLE EAST

Iran



Iran's only operational nuclear reactor is Bushehr-1, a VVER-1000 with a net capacity of 915 MW. Bushehr-1 was connected to the grid in 2011 and became commercially operational in 2013. The reactor produced 6.01 TWh in 2022, which constituted 1.7 percent of the electricity generated in the country. This is significantly more than the 2021 figure of 3.24 TWh.

There are plans to build two additional nuclear power reactors at Bushehr and the Atomic Energy Organization of Iran (AEOI) reportedly reached a preliminary agreement with Russia's

2057 - MOEA, "Energy Transition Promotion Scheme—Promote Green Energy, Increase Nature Gas, Reduce Coal-fired, Achieve Nuclear-free", Ministry of Economic Affairs, Government of Taiwan, Undated, see https://www.moea.gov.tw/MNS/english/Policy/Policy.aspx?menu_id=32904&policy_id=19, accessed 5 September 2022.

2058 - NDC, "Taiwan's Pathway to Net-Zero Emissions in 2050", Presentation, National Development Council, Government of Taiwan, 30 March 2022, accessed 28 September 2023; and Max Tingyao Lin, "Taiwan's net-zero roadmap promises $170 billion in spending, renewable expansion; more could be required", IHS Markit, S&P Global, 8 April 2022.

2059 - *Focus Taiwan*, "KMT energy mix proposal needs more explanation: MOEA deputy head", *CNA English News*, 20 September 2023, see https://focustaiwan.tw/business/202309200020, accessed 25 September 2023.

2060 - Chung-Han Yang and Chengkai Wang, "The Energy Regulation and Markets Review: Taiwan", *The Law Reviews*, 16 June 2021.

Rosatom in 2014.[2061] The first pour of concrete for the second nuclear reactor, Bushehr-2, where construction had already started in 1976, reportedly took place in 2019.[2062] However, in June 2022, the director of the AEOI told news media that "Iran began pouring concrete for the wall of the reactor of the second unit of its Bushehr Nuclear Power Plant".[2063] Preliminary work on constructing the 3rd reactor reportedly started in January 2021.[2064] According to Iranian officials, these two reactors are to be completed in 2024 and 2026 respectively.[2065] When concrete pouring commenced for Bushehr-2, the director of AEOI was quoted as saying that the "construction process had witnessed a 28-month delay".[2066]

In July 2022, AEOI announced that it had "started another project to build a completely Iranian nuclear power plant with a capacity of 360 MWe".[2067] The reactor is to be built at a "new" site called Darkhovin or Karoon in southwest Iran. Even though the reactor is described as Iranian, the origins of the design go back to joint work with European, especially French, companies.[2068] In 2016, the Head of AEOI, Ali Akbar Salehi said that "the construction model for the reactor has been inspired by one from Switzerland, based on which engineers at the AEOI have drawn up a new design for a 360MW power plant" and that the designing was "done by Iranian scientists and European companies would then evaluate and approve them".[2069]

The official launch of the project was in December 2022, and the reactor is projected to take eight years to build and cost about US$2 billion.[2070] However, the construction start as technically defined (the beginning of the concreting of the basemat of the reactor building) has not taken place yet, and, as discussed in WNISR2022, the AEOI has been planning to build such a reactor since 2008.[2071] In the past, there were also announcements about operations starting in 2015.[2072]

2061 - *WNN*, "Russia, Iran discuss further reactors", *World Nuclear News*, 14 March 2014, see https://www.world-nuclear-news.org/NN-Russia-Iran-discuss-further-reactors-1403144.html, accessed 1 August 2022.

2062 - Pamela Largue, "Tehran, Moscow begin construction of Bushehr nuclear reactor", *Power Engineering International*, 11 November 2019, see https://www.powerengineeringint.com/nuclear/tehran-moscow-begin-construction-of-bushehr-nuclear-reactor/, accessed 13 April 2020.

2063 - *FNA*, "Concrete Pouring Operations Starts at 2nd Unit of Iran's Bushehr N. Power Plant", *Farsnews Agency*, 25 June 2022, see https://www.farsnews.ir/en/news/14010404000286/Cncree-Pring-Operains-Sars-a-2nd-Uni-f-Iran's-Bshehr-N-Pwer-Plan, accessed 24 June 2023.

2064 - *Tehran Times*, "Construction of phases 2, 3 of Bushehr nuclear plant has started", 25 January 2021, see https://www.tehrantimes.com/news/457339/Construction-of-phases-2-3-of-Bushehr-nuclear-plant-has-started, accessed 1 August 2022.

2065 - Ibidem; and FNA, "Concrete Pouring Operations Starts at 2nd Unit of Iran's Bushehr N. Power Plant", 25 June 2022, op. cit.

2066 - *NEI Magazine*, "Iran begins concrete pouring for wall at Bushehr 2", 28 June 2022.

2067 - *NEI Magazine*, "Iran begins work on domestic-design NPP", *Nuclear Engineering International*, 5 July 2022, see https://www.neimagazine.com/news/newsiran-begins-work-on-domestic-design-npp-9824734, accessed 7 July 2022.

2068 - Ibidem.

2069 - Marjohn Sheikhi, "Iran to build structure for 2 new power plants in Bushehr", Mehr News Agency, 11 September 2016, see https://en.mehrnews.com/news/119639/Iran-to-build-structure-for-2-new-power-plants-in-Bushehr, accessed 24 August 2023.

2070 - *TOI* and *AFP*, "Iran starts construction on $2 billion nuclear power plant Karoon, state media says", *The Times of Israel*, 3 December 2022, see https://www.timesofisrael.com/iran-starts-construction-on-new-nuclear-power-plant-karoon-state-media-says/; and *WNN*, "Iran marks start of work for Darkhovin plant", *World Nuclear News*, 6 December 2022, see https://www.world-nuclear-news.org/Articles/Iran-marks-start-of-work-for-Darkhovin-plant; also *Associated Press*, "Iran announces start of construction on new nuclear power plant", as published on *PBS NewsHour*, 3 December 2022, see https://www.pbs.org/newshour/world/iran-announces-start-of-construction-on-new-nuclear-power-plant; all accessed 30 July 2023.

2071 - Hashem Kalantari, "Iran says designing new nuclear power plant", *Reuters*, 24 August 2008, see https://www.reuters.com/article/uk-iran-nuclear-plant-idUKKAL44586320080824, accessed 30 July 2023.

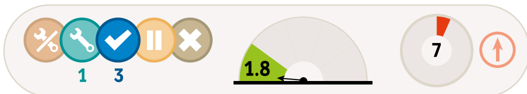
2072 - *Strategic Comments*, "Iran dismisses post-Fukushima nuclear rethink", Vol 17, Issue 3, 21 April 2011, see https://doi.org/10.1080/13567888.2011.581851, accessed 24 August 2023.

The announcement also included plans to "scale up the share of nuclear energy...to about 20 percent".[2073] Again, there are historical precedents to such announcements, and their not coming true. Back in 2004, for example, Iranian nuclear officials announced plans to "produce 7,000 MW" of nuclear power by 2021.[2074]

Iran's renewable energy capacity continues to grow slowly, and as of the end of 2022 stood at 12 GW, an increase of about 1 percent over the previous year, and a modest increase of 16 percent when compared to the situation a decade ago.[2075] Most of this capacity is hydropower, but Iran has also installed 342 MW of wind energy capacity, an increase of 10 percent compared to 2021. Solar energy has increased by 18 percent to reach a total installed capacity of 539 MW in 2022.

Together, non-hydro renewables generated 2 TWh (gross) of electrical energy, around 0.6 percent of the national total.[2076] The vast majority of power was generated from natural gas (300 TWh) and oil (31 TWh).

United Arab Emirates



The United Arab Emirates' (UAE) Barakah One Company, a joint-venture between the Emirates Nuclear Energy Corporation and the Korea Electric Power Corporation, has been building four APR-1400 reactors at Barakah. Three of these units are operating and have been declared entering commercial operation in April 2021, March 2022, and February 2023 respectively.[2077] Construction of the fourth unit started in July 2015,[2078] and it is yet to start operating. In June 2023, the Emirates Nuclear Energy Corporation announced that Unit 4 had "begun its operational readiness preparations".[2079] All reactors are delayed compared to initial projections. In 2014, the Emirates Nuclear Energy Corporation had projected that Unit 1 would "enter commercial operation in 2017, Unit 2 in 2018, Unit 3 in 2019 and the final Unit 4 in 2020".[2080] In July 2023, Barakah One announced that it had refinanced the full outstanding balance under the loan facilities extended by the Export-Import Bank of Korea.[2081]

2073 - *Pars Today*, "AEOI chief announces construction of nuclear power plant in Khuzestan", 3 December 2022.

2074 - Alfean Hardy, "Iran plans 7000MW of nuclear power", *Energy News Bulletin*, 12 May 2004, see https://www.energynewsbulletin.net/news-archive/news/1056140/iran-plans-7000mw-of-nuclear-power, accessed 24 August 2023.

2075 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

2076 - Energy Institute, "Statistical Review of World Energy 2023—Data", June 2023, op. cit.

2077 - *WNN*, "Third Barakah unit begins commercial operation", *World Nuclear News*, 24 February 2023, see https://world-nuclear-news.org/Articles/Third-Barakah-unit-begins-commercial-operation, accessed 30 July 2023.

2078 - WNISR, "Construction Start on UAE Barakah Unit 4", World Nuclear Industry Status Report, 6 September 2015, see https://www.worldnuclearreport.org/Construction-Start-on-UAE-Barakah-Unit-4.html, accessed 30 July 2023.

2079 - *NEI Magazine*, "Barakah 4 prepares for operation", *Nuclear Engineering International*, 13 June 2023, see https://www.neimagazine.com/news/newsbarakah-4-prepares-for-operation-10935008, accessed 24 July 2023.

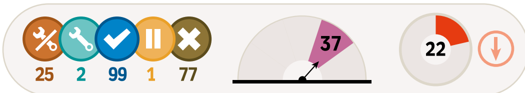
2080 - ENEC, "Unit 1 of power plant more than 57% complete", Press Release, Emirates Nuclear Energy Corporation, 17 September 2014, see https://www.enec.gov.ae/news/latest-news/unit-1-of-enecs-barakah-power-plant-now-more-than-57-complete/, accessed 10 June 2022.

2081 - ENEC, "ENEC's JV Barakah One Company successfully completes refinancing of the Barakah Nuclear Energy Plant through UAE banking partners", Press Release, Emirates Nuclear Energy Corporation, 26 June 2023, see https://www.enec.gov.ae/news/latest-news/enec-s-jv-barakah-one-company-successfully-completes-refinancing/, accessed 4 July 2023.

In 2022, nuclear reactors contributed 19.3 TWh of electricity to the UAE's grid representing 6.8 percent of total electrical energy.[2082] The corresponding figures for 2021 are 10.1 TWh and 1.3 percent. In other words, nuclear power's contribution nearly doubled. According to the Statistical Review of World Energy Data, however, nuclear energy contributed 13 percent or 20.1 TWh (gross) in 2022 and 7 percent or 10.5 TWh (gross) in 2021.[2083] There is no apparent explanation for the vastly different values for the fraction of electricity supplied by nuclear reactors.

While natural gas remains the main source of electricity generation in the country (82.5 percent)[2084], renewable generation capacity in the UAE continues to increase rapidly. Over the past decade, total capacity went from 128 MW in 2013 to 3.1 GW in 2022, an increase of 11.8 percent compared to 2021.[2085] Nearly all of this is solar energy (3 GW), including photovoltaics (2.9 GW) and concentrated solar power (100 MW). Renewables contributed 7 TWh, or 4.5 percent of all electricity supplied to UAE's grid.[2086] According to the 2023 update of its energy strategy, the UAE plans to "triple the share of renewable energy by 2030" and reach 19.8 GW of clean energy by 2030 but mentions no new nuclear targets.[2087]

EUROPEAN UNION (EU27)



The EU27 member states have gone through three nuclear construction waves (see Figure 74)—two small ones in the 1960s and the 1970s and a larger one in the 1980s (mainly in France). But over the past 30 years since 1993 only 13 reactors were connected to the grid in current EU27 Member States, half of them in Western Europe—five in France and one in Finland—the rest in Eastern and Central Europe. Only three reactors started up since 2003: after Cernavoda-2 was connected to the grid in Romania in 2007, the following reactor—the long-awaited, many times delayed Olkiluto-3 in Finland—produced its first kilowatt-hours in March 2022, and Mochovce-3 in Slovakia, where construction first started in 1985, was finally connected to the grid in January 2023.

2082 - IAEA - PRIS, "Nuclear Share of Electricity Generation in 2022", Updated 29 July 2023, see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx, accessed 30 July 2023.

2083 - Energy Institute, "Statistical Review of World Energy 2023 - Data", June 2023, op. cit.

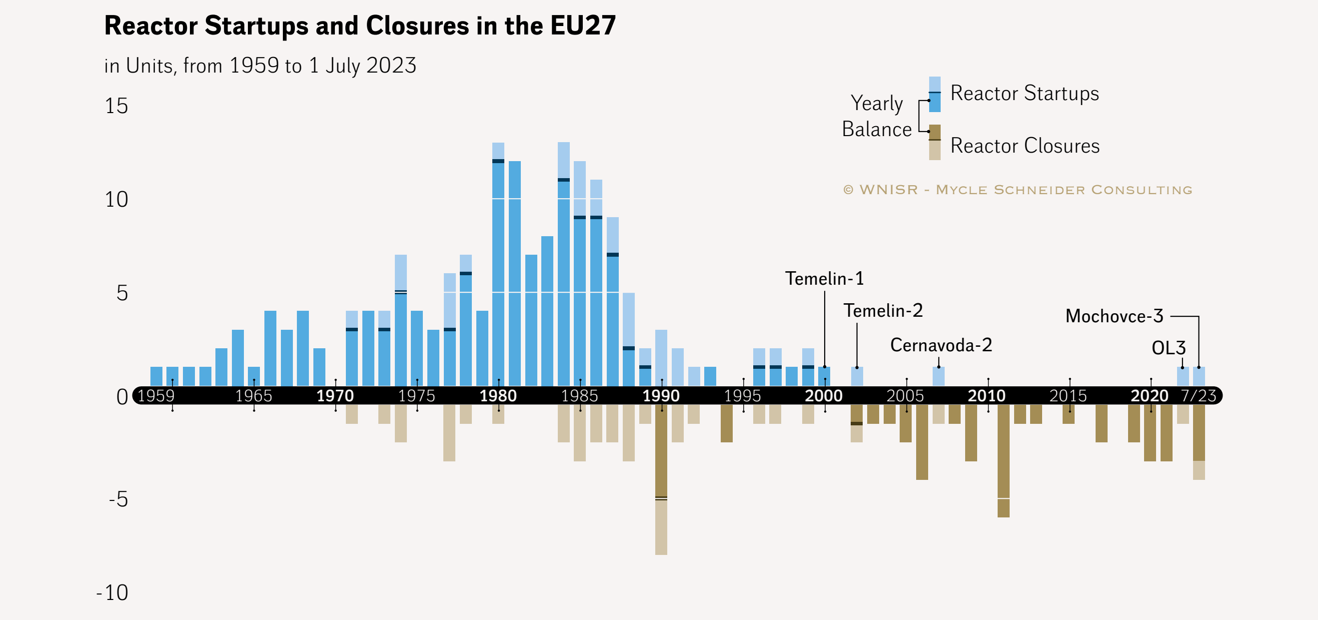
2084 - Ibidem.

2085 - IRENA, "Renewable Capacity Statistics 2023", International Renewable Energy Agency, March 2023, see https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023, accessed 30 July 2023.

2086 - Energy Institute, "Statistical Review of World Energy 2023—Data", June 2023, op. cit.

2087 - Ministry of Energy & Infrastructure, "UAE Energy Strategy 2050", United Arab Emirates Government, 14 August 2023, see https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/uae-energy-strategy-2050, accessed 27 August 2023.

Figure 74 · Nuclear Reactors Startups and Closures in the EU27, 1959–1 July 2023



Sources: WNISR, with IAEA-PRIS, 2023

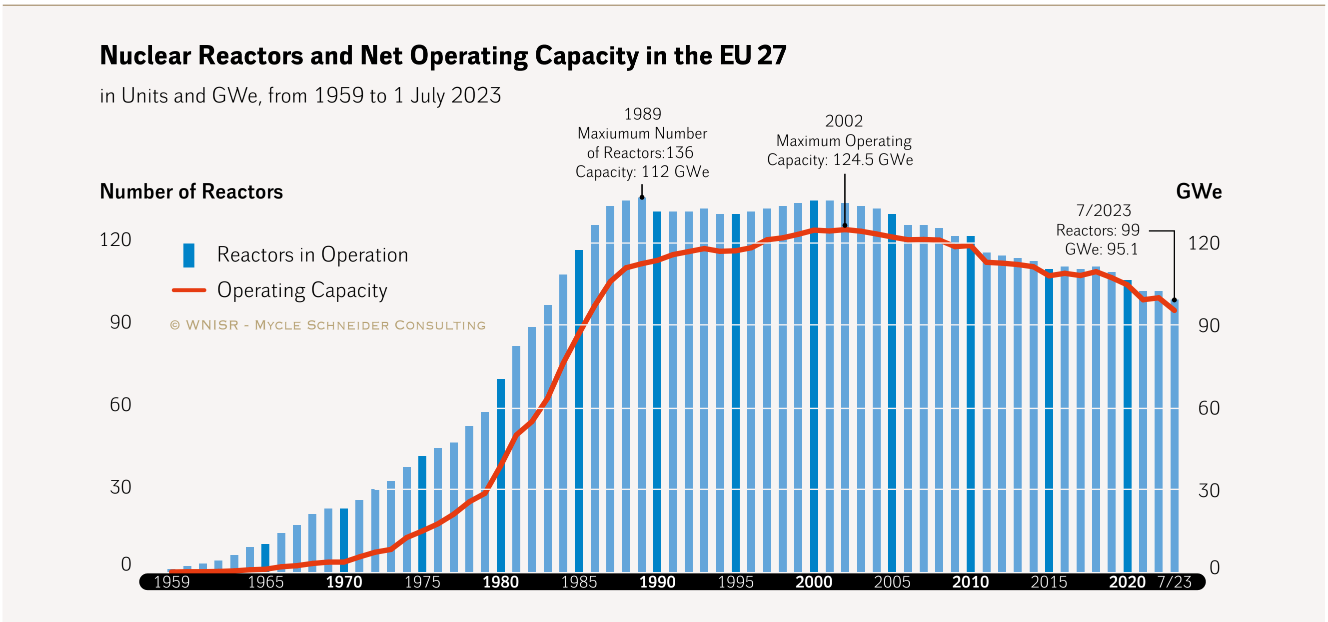
As Figure 75 shows, 99 reactors are operating[2088] in the EU27 as of mid-2023, 37 less than the historic maximum of 136 units in 1989, a drop by over one quarter. Eighty percent of the operating plants are located in six of the western countries—with 55 units[2089] in France alone—and only 20 in the six newer member states with nuclear power.

The closures of Tihange-2 in February 2023 in Belgium, and Emsland, Isar-2 and Neckarwestheim-2, all in Germany, in April 2023, brings the number of permanently closed reactors in the EU27 to 77 (68 in Western Europe, over half of which in Germany). Thirty-seven units were closed over the past 20 years from 2003 to mid-2023.

2088 - Plus one French reactor in LTO October 2021–13 July 2023. See following note.

2089 - In France, the Penly-1 reactor was offline since 2 October 2021, and therefore in LTO as of 1 July 2023, bringing the operating fleet to 55 units. It was reconnected to the grid on 13 July 2023; see EDF, "Les deux unités de production de la centrale nucléaire de Penly connectées au réseau électrique national", Press Release (in French), 14 July 2023, see https://www.edf.fr/la-centrale-nucleaire-de-penly/les-actualites-de-la-centrale-nucleaire-de-penly/les-deux-unites-de-production-de-la-centrale-nucleaire-de-penly-connectees-au-reseau-electrique-national, accessed 14 July 2023.

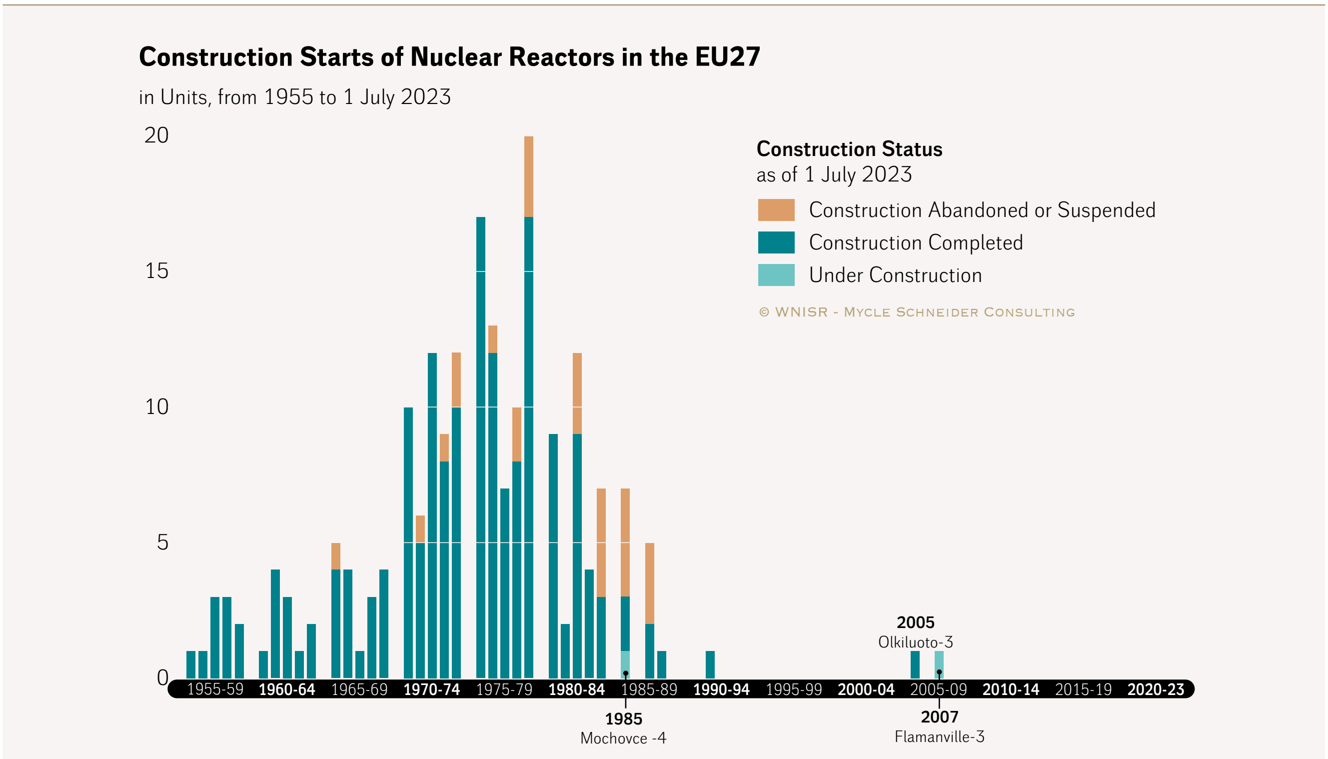
Figure 75 • Nuclear Reactors and Net Operating Capacity in the EU27



Sources: WNISR, with IAEA-PRIS, 2023

Note: As of 1 July 2023, the French reactor Penly-1 is in LTO since October 2021.

Figure 76 • Construction Starts of Nuclear Reactors in the EU27



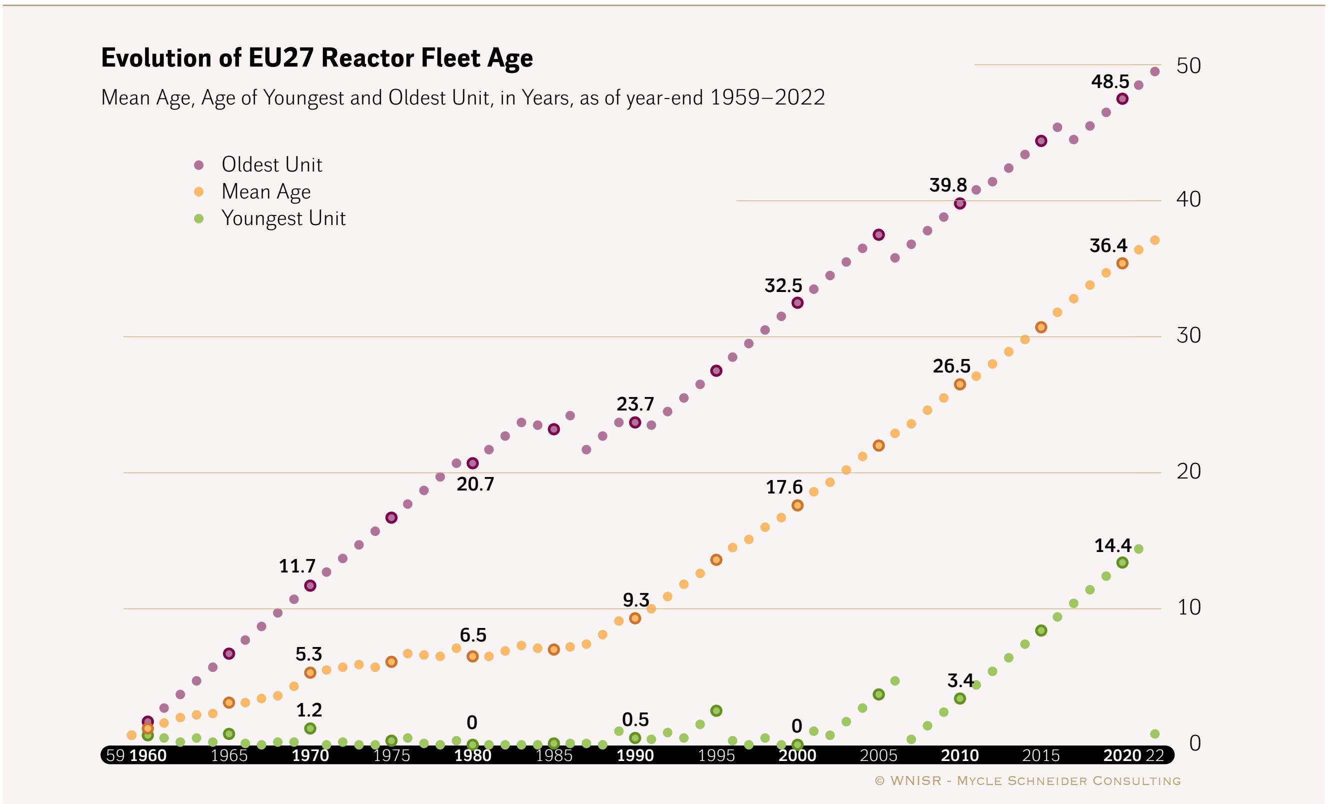
Sources: WNISR, with IAEA-PRIS, 2023

Note: Mochovce-3 & -4 construction start was first introduced as of 1985 in IAEA-PRIS, "Nuclear Power Reactors in the World – April 2016 Edition", 2016. Their construction was later suspended. See section on Slovakia.

In the EU27, in 2022, nuclear plants have generated net 580.5 TWh, a significant 17 percent decrease compared to the previous year.[2090] The "Statistical Review of World Energy" indicates a 21.6 percent share in gross generation, a drop of 3.6 percentage points compared to 2021 (25.2 percent).[2091]

Without any significant delivering newbuild program (see Figure 76), the average age of nuclear power plants has increased since the mid-80s and at mid-2023 is 37.2 years (see Figure 77 and Figure 78). Grid connection of Olkiluoto-3 in 2022, and Mochovce-3 in 2023, as well as the two reactors under construction, one in Slovakia (since 1985) and one in France (since 2007), will not significantly impact this evolution.

Figure 77 • Age Evolution of EU27 Reactor Fleet, 1959–2022



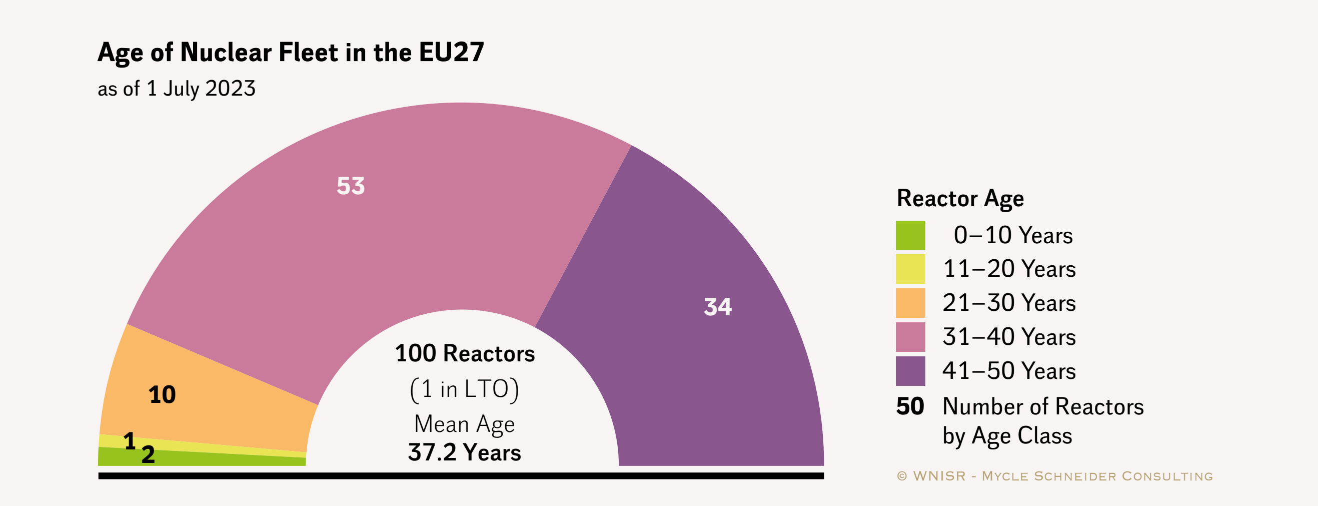
Sources: WNISR, with IAEA-PRIS, 2023

The age distribution shows that now over 85 percent—87 of 100—of the E.U.'s operating nuclear reactors have been in operation for 31 years and beyond of which 34 have been on the grid for 41 years and more.

2090 - IAEA-PRIS data.

2091 - Energy Institute, "Statistical Review of World Energy – Statistical Workbook", June 2023, op. cit.

Figure 78 • Age Distribution of the EU27 Reactor Fleet



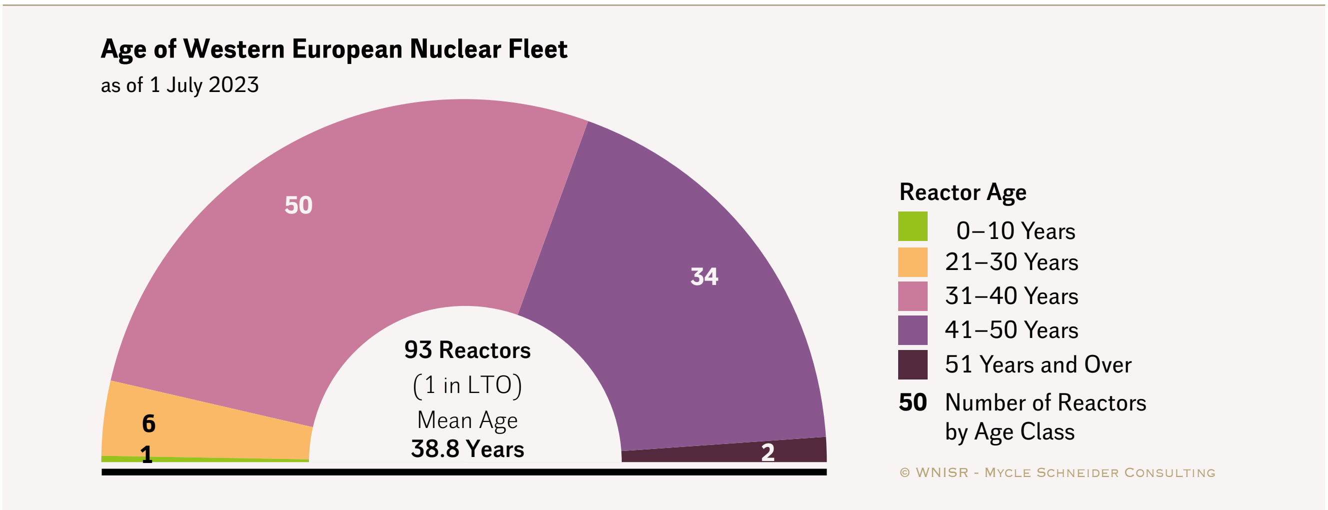
Sources: WNISR, with IAEA-PRIS, 2023

WESTERN EUROPE

As of mid-2023, 92 nuclear power reactors operated in Western Europe (including U.K. and Switzerland), 68 units fewer than in the peak years 1988–89, a 42-percent decline. One reactor was in LTO (Penly-1 in France). Two reactors were closed in the U.K. (Hinkley Point B-1 and -2, closed in August and July 2022 respectively). Five reactors were closed in the EU27, Emsland, Isar-2 and Neckarwestheim-2 in Germany in the first half-year of 2023, as well as Doel-3 and Tihange-2 in Belgium, in September 2022 and January 2023 respectively.

With Switzerland operating two reactors for over 50 years—Beznau-1 (54), Beznau-2 (close to 52)—the average age of operating reactors in Western Europe reaches 38.8 years (see Figure 79).

Figure 79 • Age Distribution of the Western European Reactor Fleet (incl. Switzerland and the U.K.)



Sources: WNISR, with IAEA-PRIS, 2023

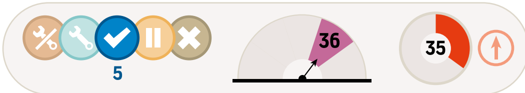
Three reactors are currently under construction, two in the U.K. (Hinkley Point C-1 and C-2) and one in France (Flamanville-3). All are European Pressurized Water Reactors (EPR) and all are many years behind their initial schedule and billions of Euros over budget (details are discussed in other chapters of the report).

The mean-age evolution of the nuclear reactor fleet in Western Europe follows the same pattern as the EU27, constantly increasing since the middle of the 1980s. The eventual startup of the three reactors currently under construction will not modify the picture significantly.

Belgium

See Focus Countries – Belgium Focus.

Finland



Nuclear reactors supplied a new record of 24.2 TWh of electricity in Finland. The nuclear share represented 35 percent in 2022, an increase of 2.2 percentage points over 2021, compared to a peak of 38.4 percent in 1986.

Finland's fifth reactor, the 1600-MW EPR at Olkiluoto (OL3)—which had been under construction since August 2005 and was originally scheduled to begin operations in 2009—was finally connected to the grid on 12 March 2022.[2092] Credit-rating agencies welcomed the development and raised TVO's rating based on scheduled commercial operation by July 2022—which did not happen. Since the much-delayed commercial production start of OL3 in April 2023, Standard & Poor's and Fitch respectively lifted TVO's rating to BB+ or confirmed it to BBB-, still the lowest investment-grade rating.[2093]

Following the pattern of countless technical problems and delays during the construction phase, the commissioning stage of OL3, planned to be completed in 2022, continued to be hampered by "unexpected" events like the untimely triggering of the boron pumps in April 2022 and "foreign material issues observed in the turbine's steam reheater" in May 2022. Therefore, according to TVO "regular electricity production" was then "to start in December 2022, instead of the previously announced start in September 2022".[2094]

Even after first grid connection, technical issues kept impacting the schedule. In August 2022, test production was facing difficulties, such as measurement errors in the voltage

2092 - WNISR, "Europe's First EPR: 13 Years Behind Schedule, Olkiluoto-3 in Finland Starts Up", World Nuclear Industry Status Report, 25 March 2022, see https://www.worldnuclearreport.org/Europe-s-First-EPR-13-Years-Behind-Schedule-Olkiluoto-3-in-Finland-Starts-Up.html, accessed 27 July 2023.

2093 - In 2022, ratings remained in a non-investment/speculative range but were raised to a "satisfactory" level in 2023, .e.g. see S&P Global Ratings, "Finnish Nuclear Producer Teollisuuden Voima Upgraded To 'BBB-' From 'BB+' On OL3 Plant Commissioning; Outlook Stable", Research Update, 26 April 2023, see https://www.tvo.fi/material/collections/20230426124450/HrvYjk6Nr/Standard__Poors_April_26,_2023.PDF; and Fitch Ratings, "Fitch Affirms Teollisuuden Voima Oyj at 'BBB-'; Outlook Stable", 19 May 2023, see https://www.tvo.fi/material/collections/20230522092126/HsYtSjJQF/Fitch_Fitch_Affirms_Teollisuuden_Voima_Oyj_at_BBB-_Outlook_Stable_-_19_May_2023.pdf; both accessed 4 November 2023.

2094 - TVO, "TVO - Olkiluoto 3 EPR's test production will continue in the end of July", Press Release, Teollisuuden Voima Oyj, 15 June 2022, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2022/olkiluoto3epr8217testproductionwillcontinueintheendofjuly.html, accessed 22 August 2022.

regulators.2095 In October 2022, cracks resulting from a yet unknown origin were found in all of the feedwater pumps that ultimately required TVO to postpone the beginning of commercial operation first by a few weeks to end-December 2022,2096 then to February 2023.[2097] Further delays occurred during the winter of 2023,[2098] until finally, on 16 April 2023, 17.5 years after construction began, OL3 generated electricity at its full capacity.[2099]

After the Russian invasion of Ukraine, Finland has been under increased pressure regarding power and gas supply from Russia. In May 2022, Russia cut power exports to Finland because Finnish utilities had not paid for delivery after sanctions put restrictions on payment methods. This led to increases in wholesale prices in Finland by €8.2 (US$$_{2022}$8.6) to €90.2 per MWh (US$94.6/MWh) over Q3 2022.[2100] Russia cut natural gas flows in the same month of May 2022.[2101] The long-awaited operation of OL3 has relieved Finnish power supply from some of this external pressure.[2102]

Finland has adopted different nuclear technologies and suppliers, as two of its operating reactors are modified VVER-V213 built by Russian contractors at Loviisa, while two are AAIII, BWR-2500 built by Asea Brown Boveri (ABB) at Olkiluoto. The OL3 European Pressurized Water Reactor (EPR) contractor is AREVA (-Siemens). After the technical bankruptcy and dismantling of AREVA Group, the French government kept AREVA S.A. to deal with the liabilities of the project.

The average age of the first four operating reactors is 44.3 years. In January 2017, operator TVO (Teollisuuden Voima Oyj) filed an application for a 20-year license extension for Olkiluoto-1 and -2 (OL1, OL2), which were connected to the grid in 1978 and 1980 respectively.[2103]

2095 - Anne Kauranen and Anna Ringstrom, "Finnish Olkiluoto 3 nuclear reactor back on grid after disturbance", *Reuters*, 29 August 2022, see https://www.reuters.com/business/energy/finnish-olkiluoto-3-nuclear-reactor-back-grid-after-disturbance-2022-08-29/, accessed 27 July 2023.

2096 - Stine Jacobsen, "Cracks found in Finnish OL3 nuclear reactor's feedwater pumps", *Reuters*, 28 October 2022, see https://www.reuters.com/business/energy/cracks-found-finnish-ol3-nuclear-reactors-feedwater-pumps-2022-10-28/, accessed 27 July 2023.

2097 - TVO, "Olkiluoto 3 EPR's electricity production will continue at the end of December at the earliest", Press Release, Teollisuuden Voima Oyj, 9 December 2022, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2022/olkiluoto3epr8217selectricityproductionwillcontinueattheendofdecemberattheearliest.html, accessed 4 November 2023.

2098 - TVO, "Olkiluoto 3 EPR's test production to continue", Press Release, Teollisuuden Voima Oyj, 21 December 2022, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2022/olkiluoto3epr8217stestproductiontocontinue.html; and David Dalton, "Regular Electricity Production At Finland EPR Plant Postponed By Five Days", *NucNet*, 15 February 2023, see https://www.nucnet.org/news/regular-electricity-production-at-finland-epr-plant-postponed-by-five-days-2-3-2023; also TVO, "Olkiluoto 3's electricity production continues after valve maintenance in March", Press Release, 16 February 2023, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2023/olkiluoto38217selectricityproductioncontinuesaftervalvemaintenanceinmarch.html; and Terje Solsvik, "Finland's OL3 nuclear power plant again delays restart", *Reuters*, 1 March 2023, see https://www.reuters.com/article/finland-energy-nuclearpower-idINL8N35917A; all accessed 4 November 2023.

2099 - TVO, "Regular electricity production has started at Olkiluoto 3 EPR", Press Release, Teollisuuden Voima Oyj, 16 April 2023, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2023/regularelectricityproductionhasstartedatolkiluoto3epr.html; and *AFP*, "Europe's largest nuclear reactor enters service in Finland after months of delays", as published in *Le Monde*, 16 April 2023, see https://www.lemonde.fr/en/europe/article/2023/04/16/europe-s-largest-nuclear-reactor-enters-service-in-finland-after-months-of-delays_6023126_143.html, accessed 27 July 2023.

2100 - Gwladys Fouche and Nora Buli, "Russia cuts power exports to Finland over failed payments", *Reuters*, 16 May 2022, see https://www.reuters.com/markets/europe/russia-cuts-power-exports-finland-over-failed-payments-2022-05-16/, accessed 27 July 2023.

2101 - Terje Solsvik, "Russia stops gas flows to Finland over payments dispute", *Reuters*, 21 May 2022, see https://www.reuters.com/business/energy/russia-stops-finland-gas-flow-over-payments-dispute-2022-05-21/, accessed 27 July 2023.

2102 - TVO, "Reasons why Olkiluoto 3 is so significant", Press Release, Teollisuuden Voima Oyj, 8 May 2023, seehttps://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2023/reasonswhyolkiluoto3issosignificant.html, accessed 3 August 2023.

2103 - TVO, "New operating license applied for Olkiluoto 1 and 2 plant units", Press Release, 26 January 2017, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2017/hNRykwgEO.html, accessed 27 July 2023.

On 20 September 2018, the government approved the lifetime extension for both units to operate until 2038.[2104]

In March 2022, Fortum, owner-operator of the Loviisa nuclear power plant, filed a license renewal application to the Finnish Ministry of Economic Affairs and Employment that requested reviews from regulatory agencies, such as the Radiation and Nuclear Safety Authority, aiming to be granted permission to operate the two units until the end of 2050.[2105] Former licenses had already been extended in 2007 and were due to expire in 2027 and 2030 respectively.[2106] In February 2023, both plants were granted operating licenses until the end of 2050, under the condition of fuel supply diversification (see below).[2107] As Loviisa-1 was first connected to the grid in 1977 and Loviisa-2 followed in 1980 that would mean 73- and 70-year operating lifetimes respectively. After having already invested €300 million (US$$_{2023}$327 million) into refurbishment over the past five years, Fortum estimates that another €1 billion (~US$$_{2023}$1.1 billion) will be necessary for continued operation. Plans to operate a low- and intermediate waste level facility onsite until 2090 are still pending authorization.[2108]

Fuel for Loviisa has been provided by Russian supplier TVEL (formerly Technopromexport) since the start of operations, with a brief interruption, when British Nuclear Fuel Limited (then the owner of Westinghouse[2109]) supplied fuel for seven reloads from 2001 to 2007.[2110] Current contracts with TVEL were set to expire in accordance with former operating licenses (2027 and 2030, respectively), and Fortum plans on continuing to purchase fuel from Russia. Early November 2022, Matti Kattainen, Fortum's Head of Nuclear Power, said that they would "look at who's the most suitable fuel supplier at the latest when the current contract expires."[2111] Then on 22 November 2022, Fortum announced that an agreement had been signed with Westinghouse "for the design, licensing, and supply of a new fuel type" for Loviisa, and reiterated that a tendering process for the fuel supply succeeding the current contract with TVEL would be launched at a later stage.[2112] This announcement preceded the announcement

2104 - TVO, "Finnish Government approves extension of operating licences for OL1 and OL2 plant units", Press Release, 20 September 2018, see https://www.tvo.fi/news/2043, accessed 25 October 2018.

2105 - Fortum, "Fortum submits the Loviisa nuclear power plant operating licence application to the Government", Press Release, 18 March 2022, see https://www.fortum.com/media/2022/03/fortum-submits-loviisa-nuclear-power-plant-operating-licence-application-government, accessed 18 March 2022.

2106 - Ministry of Economic Affairs and Employment, "Operating licences of Loviisa 1 and 2 expire in 2027 and 2030", April 2022, see https://tem.fi/en/loviisa-1-and-2-operating-licence, accessed 27 April 2022.

2107 - *YLE News*, "Fortum gets Loviisa nuclear plant permit extension", 16 February 2023, see https://yle.fi/a/74-20018411, accessed 3 August 2023.

2108 - Fortum, "The Finnish Government has granted a new operating licence for Fortum's Loviisa nuclear power plant", 16 February 2023, see https://www.fortum.com/media/2023/02/finnish-government-has-granted-new-operating-licence-fortums-loviisa-nuclear-power-plant, accessed 27 July 2023; and *WNN*, "Fortum granted licence extension for Loviisa", 16 February 2023, see https://www.world-nuclear-news.org/Articles/Fortum-granted-licence-extension-for-Loviisa?feed=feed, accessed 19 February 2023.

2109 - Christopher Rhodes, David Hough and Louise Butcher, "Privatisation", Research Paper 14/61, House of Commons Library, November 2014, see https://commonslibrary.parliament.uk/research-briefings/rp14-61/, accessed 4 November 2023.

2110 - Heidi Lindroth, "Operational experience of Loviisa Nuclear Fuel and Long-term refuelling strategy", Fortum Power and Heat Oy, presented at the 10. International conference on WWER fuel performance, modelling and experimental support, 7–14 September 2013, , 11 January 2013, see https://inis.iaea.org/collection/NCLCollectionStore/_Public/44/122/44122435.pdf, accessed 3 August 2023.

2111 - *NEI Magazine*, "Fortum will use Russian nuclear fuel until 2030", *Nuclear Engineering International*, 10 November 2022, see https://www.neimagazine.com/news/newsfortum-will-use-russian-nuclear-fuel-until-2030-10284929, accessed 3 January 2023.

2112 - Fortum, "Fortum and Westinghouse Electric Company sign an agreement for the design and supply of a new fuel type for the Loviisa power plant", Press Release, 22 November 2022, see https://www.fortum.com/media/2022/11/fortum-and-westinghouse-electric-company-sign-agreement-design-and-supply-new-fuel-type-loviisa-power-plant, accessed 27 July 2023.

of the lifetime extensions at Loviisa that were granted under the condition that the fuel supply be diversified.[2113] Fortum proceeded to pull out of the Russian market, and attempted to sell its Russian assets, but had to write off a total of US$1.9 billion in May 2023 after the assets had been seized by Russian authorities.[2114]

In October 2022, Fortum commissioned a two-year feasibility study to examine potential new build possibilities for Small Modular Reactors (SMRs) and large reactors in Sweden and Finland.[2115] So far, several announcements and Memorandums of Understanding (MoU) have come from this feasibility study, signed with various potential partners. In November 2022, Fortum and Helsinki-based energy company Helen said there were initiating a "joint study to explore the prerequisites for collaboration in nuclear power and small modular reactors".[2116] Early December 2022, EDF and Fortum announced their intentions to "study opportunities for cooperation for the development of [EPR and SMRs] […] projects in Finland and Sweden".[2117] In the same month, Kärnful Next, a Swedish nuclear-only electricity supplier, announced the signature of an MoU with Fortum to "jointly explore opportunities in new nuclear for developing [SMRs] in Sweden."[2118] Then on 21 March 2023, Fortum and Rolls-Royce SMR said they had signed an MoU to also "jointly explore the opportunities for the deployment of [SMRs] in Finland and Sweden." Rolls-Royce is currently developing a 470-MW SMR.[2119] Two days later, another MoU was announced with a non-nuclear company, Finnish steel manufacturer Outokumpo, to "explore the decarbonisation of […] steel manufacturing operations with emerging nuclear technologies, such as [SMR]."[2120] On 30 May 2023, Fortum extended an MoU, originally signed in 2018 with Korea Hydro & Nuclear Power (KHNP), by a "joint exploration of new nuclear".[2121] Only a few days later, on 7 June 2023, another MoU was signed, this time with Westinghouse, to "explore the potential prerequisites for new nuclear in Finland and

2113 - *YLE News*, "Fortum Gets Loviisa Nuclear Plant Permit Extension", 16 February 2023, op. cit.

2114 - Louise Breusch Rasmussen, "Fortum to write off $1.9 billion after Russia seized assets", *Reuters*, 11 May 2023, see https://www.reuters.com/business/energy/fortums-q1-core-profit-beats-estimates-2023-05-11/, accessed 3 August 2023.

2115 - Fortum, "Fortum launches a feasibility study to explore prerequisites for new nuclear", Press Release,, 17 October 2022, see https://www.fortum.com/media/2022/10/fortum-launches-feasibility-study-explore-prerequisites-new-nuclear, accessed 27 July 2023.

2116 - Forum, "Fortum and Helen to explore potential cooperation in small modular reactors", Press Release, 25 November 2022, see https://www.fortum.com/media/2022/11/fortum-and-helen-explore-potential-cooperation-small-modular-reactors; and Helen, "Helen and Fortum are looking into potential SMR cooperation", Press Release, 25 November 2022, see https://www.helen.fi/en/news/2022/helen-and-fortum-are-looking-into-potential-smr-cooperation, accessed 4 November 2023.

2117 - EDF, "EDF and Fortum sign a Framework Cooperation Agreement for Nuclear New Build in Finland and Sweden", Press Release, 8 December 2022, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-and-fortum-sign-a-framework-cooperation-agreement-for-nuclear-new-build-in-finland-and-sweden, accessed 8 August 2023.

2118 - Kärnfull Next and Fortum, "KNXT x Fortum", Press Release, 15 December 2022, see https://www.knxt.se/fortum, accessed 27 July 2023.

2119 - Fortum, "Fortum and Rolls-Royce SMR to explore joint opportunities for SMRs in Finland and Sweden", Press Release, 21 March 2023, see https://www.fortum.com/media/2023/03/fortum-and-rolls-royce-smr-explore-joint-opportunities-smrs-finland-and-sweden, accessed 3 August 2023.

2120 - Fortum, "Fortum and Outokumpu partner to accelerate industrial decarbonisation in stainless steel production", Press Release, 23 March 2023, see https://www.fortum.com/media/2023/03/fortum-and-outokumpu-partner-accelerate-industrial-decarbonisation-stainless-steel-production, accessed 3 August 2023.

2121 - Fortum, "Fortum and KHNP have signed a Memorandum of Understanding on cooperation on nuclear power", Press Release, 31 May 2023, see https://www.fortum.com/media/2023/05/fortum-and-khnp-have-signed-memorandum-understanding-cooperation-nuclear-power, accessed 4 November 2023.

Sweden".[2122] None of these MoUs are binding, and no indications until when potential final investment decisions are to be expected were disclosed.

Fennovoima's Hanhikivi Project Cancelled

In 2007, the group Fennovoima was set up as a non-profit cooperative of power companies and industry.[2123] In March 2014, Russian state nuclear operator Rosatom, through subsidiary company RAOS Voima Oy, completed the purchase of 34 percent of the Finnish company Fennovoima for an undisclosed price,[2124] and then in April 2014 a "binding decision to construct" Hanhikivi-1, a 1,200 MW AES-2006 reactor, was announced.[2125]

Following repeated delays, on 28 April 2021, Fennovoima submitted an updated application to the Finnish regulator STUK (Säteilyturvakeskus) for a construction license with work to start in 2023, and commercial operation by 2029.[2126]

However, following Russia's full-scale invasion of Ukraine, on 2 May 2022 Fennovoima announced that the contract of plant delivery and cooperation with RAOS Project on Hanhikivi-1 was terminated "with immediate effect".[2127] The contract cancellation will no doubt lead to a lengthy legal battle between stakeholders. Head of Rosatom, Alexei Likachev, said that "all the money that was spent in Finland will be billed" and that Rosatom "of course [...] will take legal steps."[2128] By August 2022, Rosatom said it had filed six lawsuits totaling US$3 billion, and Fennovoima had countered with several filings adding up to €2 billion (US$$_{2022}$2.1 billion).[2129] In December 2022, an independent dispute review board—a standard element of contracts for large-scale projects—concluded that contract termination had been unlawful. Fennovoima acknowledged the board's recommendation but emphasized that it was "neither final nor binding".[2130]

The Olkiluoto-3 (OL3) Saga

In December 2003, Finland became the first country in Western Europe to order a new nuclear reactor since 1988. AREVA NP, then a joint venture owned 66 percent by AREVA and 34 percent

2122 - Fortum, "Fortum and Westinghouse to explore possibilities for new nuclear in Finland and Sweden", Press Release, 7 June 2023, see https://www.fortum.com/media/2023/06/fortum-and-westinghouse-explore-possibilities-new-nuclear-finland-and-sweden, accessed 4 November 2023.

2123 - Caroline Peachey, "Clearing the way for Finland's next nuclear power plant", *Modern Power Systems*, 26 March 2018, see https://www.modernpowersystems.com/features/featureclearing-the-way-for-finlands-next-nuclear-power-plant-6094892/, accessed 21 August 2022.

2124 - Fennovoima, "Rosatom Acquired 34% Share of Fennovoima", Press Release, 27 March 2014.

2125 - David Dalton, "Fennovoima Owners Make Binding Decision To Proceed With Hanhikivi-1", *NucNet*, 15 April 2014, see https://www.nucnet.org/news/fennovoima-owners-make-binding-decision-to-proceed-with-hanhikivi-1, accessed 25 May 2022.

2126 - Fennovoima, "Fennovoima updates the Construction License Application", Press Release, 28 April 2021.

2127 - Fennovoima, "Fennovoima has terminated the contract for the delivery of the Hanhikivi 1 nuclear power plant with Rosatom", Press Release, 2 May 2022.

2128 - Thomas Nilsen, "Rosatom wants to get back its investment in Finnish not-to-be-built NPP", *The Barents Observer*, 24 June 2022, see https://thebarentsobserver.com/en/nuclear-safety/2022/06/rosatom-wants-get-back-its-investment-finnish-not-be-built-npp, accessed 27 June 2023.

2129 - Anne Kauranen, "UPDATE 2-Rosatom and Finnish partner in dispute for damages for nuclear project", Reuters, 23 August 2022, see https://www.reuters.com/article/finland-russia-nuclearpower-idUSL8N2ZZ177, accessed 27 July 2023.

2130 - David Dalton, "Contract Cancellation Was Unlawful, Says Independent Review Board", *NucNet*, 16 December 2022, see https://www.nucnet.org/news/contract-cancellation-was-unlawful-says-independent-review-board-12-5-2022, accessed 3 August 2023.

by Siemens, was contracted to build the EPR at OL3 under a fixed-price, turnkey contract with the utility TVO. Siemens quit the consortium in March 2011 and announced in September 2011 that it was abandoning the nuclear sector entirely.[2131] After the 2015 technical bankruptcy of the AREVA Group, in which the cost overruns of Olkiluoto had played a large part, the majority shareholder, the French Government, decided to integrate the reactor-building division under "new-old name" Framatome into a subsidiary majority-owned by state utility EDF.

However, EDF made it clear that it would not take over the billions of euros' liabilities linked to OL3.[2132] Thus, it was decided that the financial liability for OL3 and associated risks would stay with AREVA S.A. after the sale of AREVA NP and the creation of a new company AREVA Holding, now named Orano, that focuses on nuclear fuel and waste management services, very similar to the old COGEMA.

OL3 construction started in August 2005, with operations planned from 2009. However, that date—and many other dates—passed (see previous WNISR editions for details).

In March 2021, fuel was finally loaded into the OL3 reactor, with grid connection announced in mid-May 2021 for October 2021.[2133] By the end of July 2021, startup had already been pushed back by another month to November 2021, "due to turbine overhaul".[2134]

On 17 May 2021, TVO announced that it had reached a consensus settlement agreement with the Areva–Siemens consortium.[2135] Negotiations had been underway since summer 2020 on the terms of the OL3 EPR project-completion. Critical to the goal was agreement for an additional €600 million (US736_{2021}$ million) to be made available from the AREVA companies' trust mechanism as of the beginning of January 2021. Other key issues agreed included that both parties are to cover their own costs from July 2021 until end of February 2022, and that in case the consortium companies do not complete the OL3 EPR project until the end of February 2022, they would pay additional compensation for delays, depending on the date of completion.[2136] The deadline was missed once again. Further financial arrangements have not been communicated. On 16 April 2023, OL-3 finally produced electricity at full capacity for the first time.[2137]

2131 - *WNN*, "Siemens quits the nuclear game", *World Nuclear News*, 19 September 2011, see https://www.world-nuclear-news.org/Articles/Siemens-quits-the-nuclear-game, accessed 29 August 2022.

2132 - David Jolly, "EDF, World's Biggest Nuclear Operator, Will Bid for AReva's Reactor Business", *The New York Times*, 19 May 2015, see https://www.nytimes.com/2015/05/20/business/dealbook/edf-areva-france-nuclear-merger-reactor-takeover-epr.html, accessed 25 May 2023.

2133 - TVO, "The terms of the OL3 EPR project completion have been agreed", Press Release, 17 May 2021, seehttps://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/thetermsoftheol3eprprojectcompletionhavebeenagreed.html, accessed 3 June 2021.

2134 - TVO, "The regular electricity production of the OL3 EPR will be postponed for a month due to turbine overhaul", Press Release, 30 July 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/theregularelectricityproductionoftheol3eprwillbepostponedforamonthduetoturbineoverhaul.html, accessed 30 July 2021.

2135 - *NEI Magazine*, "TVO and Areva-Siemens reach consensus on OL3", *Nuclear Engineering International*, 20 May 2021, see https://www.neimagazine.com/news/newstvo-and-areva-siemens-reach-consensus-on-ol3-8757426, accessed 27 July 2023.

2136 - Ibidem.

2137 - TVO, "Regular electricity production has started at Olkiluoto 3 EPR", Press Release, 16 April 2023, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2023/regularelectricityproductionhasstartedatolkiluoto3epr.html, accessed 27 July 2023.

Finland produced a total of 73 TWh of electricity in 2022. Nuclear power had the highest share at 34 percent, followed by biomass and hydro (each 19 percent), wind (17 percent), coal (4 percent), gas (2 percent), other fossil fuels (5 percent) and solar (0.4 percent).[2138]

In the past, Finland was a net importer of electricity, mainly from Russia and Sweden. Russia has cut-off electricity transmission, and the commissioning of OL3 eases tensions for the country that plans to be a net exporter by 2030. Further, Finland plans to fully decarbonize its energy system by 2035, aiming for significantly increased renewable power generation compared to 2022 values, from 12.41 TWh to 30 TWh of wind and from just 0.3 TWh to 3.4 TWh of solar.[2139]

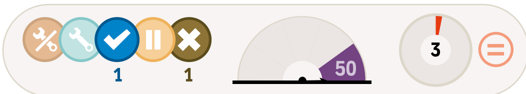
France

See Focus Countries – France Focus.

Germany

See Focus Countries – Germany Focus.

The Netherlands



The Netherlands operates a single, 50-year-old 482 MW PWR at Borssele that provided 3.9 TWh of electricity in 2022 (3.6 TWh in 2021, and a maximum of 4.0 TWh in 2009), corresponding to 3.3 percent of the country's electricity, compared to the historic maximum of 6.2 percent in 1986, when the country still also operated a 60 MW BWR at Dodewaard. The Dodewaard unit operated between 1968 and 1997. Since April 2003, all the spent fuel has been removed, and the site entered its 40-year safe enclosure period in June 2005, after which the plant should be dismantled.[2140] (See Decommissioning Status Report in WNISR2022). The government administration is evaluating several newbuild options, large reactors as well as Small Modular Reactors (SMR).

While Borssele's operating license is valid for an indefinite period, its initial safety report covered a 40-year operational lifetime, equating to the decommissioning of the plant in 2013, but in late 2006, the owner, its shareholders, and the Government reached an agreement, formalized as the "Borssele Covenant", to allow operation of the reactor to continue until 31 December 2033 provided certain conditions are met.[2141] Amongst these conditions were

2138 - Ember, "Finland electricity generation by source", Ember Electricity Data Explorer, 2023, see https://ember-climate.org/countries-and-regions/regions/european-union/, accessed 3 August 2023.

2139 - IEA, "Finland 2023 Energy Policy Review", International Energy Agency, 2023, see https://www.oecd-ilibrary.org/energy/finland-2023-energy-policy-review_d435fa51-en, accessed 27 July 2023.

2140 - IAEA, "Country Nuclear Power Profiles—The Netherlands", Updated 2021, see https://cnpp.iaea.org/countryprofiles/Netherlands/Netherlands.htm, accessed 10 August 2022.

2141 - WNA, "Nuclear Power in the Netherlands", World Nuclear Association, April 2022, see https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/netherlands.aspx, accessed 12 July 2022; and Authority for Nuclear Safety and Radiation Protection, "Borssele: Possible extension of nuclear power plant's operating life", Undated, see https://english.autoriteitnvs.nl/topics/borssele-possible-extension-of-nuclear-power-plant-s-operating-life; also State Secretary for Housing, Spatial Planning and the Environment, Minister of Economic Affairs, EPZ, Essent Energie, Delta Energy B.V., "Convenant Kerncentrale Borssele", *Staatscourant*, n. 136, p. 29 (in Dutch), 17 July 2006, see https://zoek.officielebekendmakingen.nl/stcrt-2006-136-p29-SC76083.pdf, both accessed 10 August 2022.

enforced actions that Borssele "remain [...] amongst the 25% safest water-cooled and water-moderated power reactors in the E.U., the US, and Canada" and that then-shareholding utilities Delta and Essent invest over €100 million (US$$_{2006}$125 million) each into "sustainable energy management policies" and "additional innovative projects".[2142] Today, Borssele is owned by Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ), a joint-venture of a subsidiary of German utility RWE and Provinciale Zeeuwsche Electriciteits-Maatschappij (PZEM)-former Delta, which is in turn held by Czech utility EPH.[2143]

In 2023, two missions from the IAEA visited the plant. The Operational Safety Review Team (OSART) mission, looking at operational safety, concluded in February 2023 that while there were some good practices at the plant, there was still necessity for continued improvement, especially regarding the implementation of operator support systems and plant radiation protection practices.[2144] The IRRS mission that was conducted in June 2023, assessed a high level of safety but pointed the Dutch regulators towards some possible management procedure improvements, especially to "successfully enhance their regulatory framework in the challenging environment posed by the enlargement of the nuclear power program".[2145] This "enlargement" has been subject of ongoing debate for several years, as discussed below.

The country's 2016-Energy Report assessed that "under the current market conditions, there is no demand for a new nuclear power plant, however the cabinet does not rule out new nuclear technologies being deployed in the future, as long as they are safe."[2146] In its "Integrated National Energy and Climate Plan 2021-2030" issued in 2019, the Government indicated that "A number of studies reveal that for 2050, nuclear power could be a cost-effective option and that a positive business case could be one of the long-term options. Given the lead times, additional nuclear power for 2030 does not seem likely in the Netherlands."[2147] The plan expects renewables to provide 70 percent of electricity by 2030, despite concern over the "limited availability of renewable sources in the Netherlands" and targets a 100-percent renewable electricity generation by 2050 with offshore wind delivering the lion share. In 2022, non-hydro renewables produced 48.3 TWh, or more than a third of all electricity generation (122 TWh), compared to 40.4 TWh in 2021.[2148]

2142 - Government of the Netherlands, "Convenant Kerncentrale Borssele", Staatscourant, No. 136, 17 July 2006 (in Dutch), see https://zoek.officielebekendmakingen.nl/stcrt-2006-136-p29-SC76083.pdf, accessed 11 August 2022.

2143 - ANVS, "Kerncentrale Borssele" Autoriteit Nucleaire Veiligheid en Stralingsbescherming/Authority for Nuclear Safety and Radiation Protection of the Netherlands, Undated (in Dutch), see https://www.autoriteitnvs.nl/onderwerpen/kerncentrale-borssele-epz; and EP NL, "About Us", EP Netherlands, 2023, see https://epnl.nl/about-us/; also PZEM, "Over PZEM", PZEM Energy Company B.V., 2023 (in Dutch), see https://www.pzem.nl/nl/over-pzem/, all accessed 21 August 2023.

2144 - IAEA, "IAEA Sees Commitment to Operational Safety at Netherlands' Borssele Nuclear Power Plant, Encourages Continued Improvement", Press Release 12/2023, International Atomic Energy Agency, 9 February 2023, see https://www.iaea.org/newscenter/pressreleases/iaea-sees-commitment-to-operational-safety-at-netherlands-borssele-nuclear-power-plant-encourages-continued-improvement, accessed 25 April 2023.

2145 - IAEA, "IAEA Mission Says the Netherlands Is Committed to a High Level of Safety, Sees Areas for Further Enhancement", Press Release 56/2023, International Atomic Energy Agency, 16 June 2023, see https://www.iaea.org/newscenter/pressreleases/iaea-mission-says-the-netherlands-is-committed-to-a-high-level-of-safety-sees-areas-for-further-enhancement, accessed 23 June 2023.

2146 - Ministry of Economic Affairs of the Netherlands, "Energy Report—Transition to sustainable energy", 28 April 2022, see https://www.government.nl/binaries/government/documenten/reports/2016/04/28/energy-report-transition-tot-sustainable-energy/energy-report-transition-to-sustainable-energy.pdf, accessed 12 August 2022.

2147 - Ministry of Economic Affairs and Climate Policy, "Integrated National Energy and Climate Plan 2021-2030", Dutch Government, September 2020, see https://energy.ec.europa.eu/system/files/2020-03/nl_final_necp_main_en_0.pdf, accessed 12 August 2022.

2148 - Gross Generation from Energy Institute, "Statistical Review of World Energy 2023—72nd Edition", June 2023, see https://www.energyinst.org/statistical-review, accessed 30 July 2023.

In recent years, the Dutch Government has been drawing closer attention to the possibility of continuing nuclear production beyond 2033, when the country's only existing nuclear power plant is expected to close. Following a motion passed by the Parliament to solicit the Cabinet's intervention in persuading companies to invest in nuclear power, then Minister of Economic Affairs and Climate Policy, Eric Wiebes, commissioned various studies on the potential role of nuclear power in the Netherlands. A few weeks after the publication of an Enco report on 1 September 2020, Minister Wiebes—whose party "wants up to 10 new nuclear plants to be built"—informed Parliament of the findings and the launch of procedures to allow a market consultation on nuclear newbuild.[2149] The study concluded that nuclear "could play an important role in the future energy mix of the Netherlands" and argued that both large units and SMRs would be "cheaper" than renewable technologies.[2150]

Another study commissioned by Minister Wiebes from Berenschot and Kalavasta concluded, on the contrary, that "nuclear energy is more expensive, except when nuclear power always takes precedence over the electricity grid and the government assumes a large part of the financial risks" as summarized by *Nuclear Engineering International* (*NEI*).[2151]

Dutch nuclear operator Elektriciteits Produktiemaatschappij Zuid-Nederland (EPZ), co-owned by PZEM (70 percent) and German utility RWE (30 percent) via Energy Resources Holding (ERH),[2152] proposed in November 2020 the extension of Dutch nuclear operations to tackle the challenge of climate neutrality in the Netherlands. EPZ argued that this could either be achieved by again extending the operational lifetime of Borssele for another 10 to 20 years. EPZ proposes new build as another option, according to which the government would need to invest into the construction of new nuclear reactors, the favored option being two new nuclear power plants of Generation III-type of around 1.5 GW capacity each – increasing current installed capacity sixfold. This would correspond to current newbuild projects of European Pressurized Water Reactors (EPR) or Advanced Pressurized Water Reactors (APR), "safe and reliable" technologies according to EPZ.[2153]

EPZ envisioned costs of €8–10 billion (US$$_{2020}$9.3–11.6 billion) and construction duration of eight years per new reactor, "if the project is properly implemented". The company also suggested a combined enactment of both options, putting forward the assumption that this would cover about 25 percent of the country's electricity demand by around 2035.[2154] A lifetime extension of 10 to 20 years would result in nuclear operation at Borssele of at least 70 years. As the current legislation prohibits the regulator to even consider an application for further

2149 - *NEI Magazine*, "Netherlands considers more nuclear power", *Nuclear Engineering International*, 28 September 2020, see https://www.neimagazine.com/news/newsnetherlands-pushes-for-more-nuclear-8153490, accessed 22 August 2023.

2150 - Enco, "Possible Role of Nuclear in the Dutch Energy Mix in the Future", commissioned by Ministry of Economic Affairs and Climate Policy of the Netherlands, September 2020, see https://www.tweedekamer.nl/downloads/document?id=66a4f4e8-5a8f-4638-a4c7-7a4225c8ecc9&title=Possible%20role%20of%20nuclear%20in%20de%20Dutch%20energy%20mix%20in%20the%20future.pdf, accessed 22 August 2023.

2151 - *NEI Magazine*, "Netherlands considers more nuclear power", 28 September 2020, see https://www.neimagazine.com/news/newsnetherlands-pushes-for-more-nuclear-8153490; and *WNN*, "Dutch minister presents report on new nuclear", 28 September 2020, see https://world-nuclear-news.org/Articles/Dutch-minister-presents-report-on-new-nuclear; both accessed 12 August 2022.

2152 - Authority for Nuclear Safety and Radiation Protection, "Convention on Nuclear Safety (CNS)—National Report of the Kingdom of the Netherlands for the Eight Review Meeting", 2019, see https://zoek.officielebekendmakingen.nl/blg-894160.pdf, accessed 10 August 2022.

2153 - EPZ, "Visie EPS op kernenergie in Nederland na 2033", Elektriciteits Produktiemaatschappij Zuid-Nederland, November 2020 (in Dutch), see https://www.epz.nl/app/uploads/2021/04/Visie-EPZ-op-kernenergie-in-Nederland-na-2033.pdf, accessed 12 July 2022.

2154 - Ibidem.

prolonged operation at Borssele,[2155] the Dutch Parliament decided to inquire into the legislative changes required to allow a lifetime extension in 2020.[2156] Further operation of Borssele would require the amendments of the Nuclear Energy Act and the Convenant, as well as a license renewal to update underlying safety report forms.[2157] In December 2022, operator EPZ applied for a grant to conduct a feasibility study on the operation of Borssele post 2033.[2158]

In terms of nuclear newbuild, various plans had been made to attempt the construction of a new plant (see previous WNISR editions), but no progress been made since 2012, when Delta—then majority shareholder—put plans on ice "for at least two years" citing unfavorable investment conditions and low energy prices.[2159]

In a 2021-market consultation, commissioned by the House of Representatives prior to the new administration taking office, consulting firm KPMG stated that "private financing without extensive government guarantees would be difficult or impossible to achieve [as] a large nuclear power plant is too big an investment for many private investors, and has too long a horizon."[2160] The report further indicates the focus of nuclear new build on "proven" technologies of Generation III+ designs, such as the EPR or APR, as this would limit first-of-a-kind (FOAK) cost risks in comparison to implementing a completely new reactor design. While the report itemizes several Gen-III designs, Russian and Chinese technologies have been placed "out of scope" at the request of the Ministry of Economic Affairs, thus pointing to EDF, Westinghouse and KEPCO as "obvious options". Nonetheless, without consensus on "best" design, and given that "a choice can only be made once a sufficient number of projects have actually been completed", it was expected that a choice would only be possible by 2023.

In late 2021, the new Dutch government followed EPZ's original proposal in their coalition agreement. Official governmental plans now include an undefined lifetime extension for Borssele and the construction of two new reactors to achieve the envisioned CO_2 reduction goals of -70 percent by 2035 and -80 percent by 2040. A total of €5 billion (US$$_{2021}$5.9 billion) is planned to be spent by the Dutch government until 2030 to facilitate the construction of the new plants. However, the current legislative period ends in 2025 until when €500 million (US$$_{2021}$592 million) are to be spent for nuclear newbuild.[2161]

2155 - ANVS, "Borssele: Possible Extension of Nuclear Power Plant's Operating Life", Autoriteit Nucleaire Veiligheid en Stralingsbescherming/Authority for Nuclear Safety and Radiation Protection, Undated, see https://english.autoriteitnvs.nl/topics/borssele-possible-extension-of-nuclear-power-plant-s-operating-life, accessed 1 August 2022.

2156 - IAEA, "Country Nuclear Power Profiles—The Netherlands", 2021, op. cit.

2157 - ANVS, "Borssele: Possible extension of nuclear power plant's operating life", Autoriteit Nucleaire Veiligheid en Stralingsbescherming/Authority for Nuclear Safety and Radiation Protection of the Netherlands, Undated, see https://english.autoriteitnvs.nl/topics/borssele-possible-extension-of-nuclear-power-plant-s-operating-life, accessed 22 August 2023.

2158 - EPZ, "EPZ is verheugd met voortvarende stappen kabinet", Press Release (in Dutch), Elektriciteits-Produktiemaatschappij Zuid-Nederland, 9 December 2022, see https://www.epz.nl/actueel/epz-is-verheugd-met-de-voortvarende-stappen-die-het-kabinet-zet-om-de-bouw-van-twee-nieuwe-kerncentrales-in-borssele-mogelijk-te-maken/, accessed 22 August 2023.

2159 - *SPIEGEL ONLINE*, "Bau des Atomkraftwerks in Borssele verschoben", 24 January 2012 (in German), see https://www.spiegel.de/wissenschaft/technik/niederlande-bau-des-atomkraftwerks-in-borssele-verschoben-a-811010.html, accessed 12 July 2022; and *Uranium Intelligence Weekly*, "Netherlands", 23 January 2012.

2160 - KPMG, "Nuclear Energy Market Consultation", commissioned by the Ministry of Economic Affairs and Climate Policy, Government of the Netherlands, 1 July 2021, see https://www.government.nl/documents/reports/2021/07/01/market-consultation-nuclear-energy; and *NEI* Magazine, "KPMG Looks at Feasibility of New Build in Netherlands", 12 July 2021, see https://www.neimagazine.com/news/newskpmg-looks-at-feasibility-of-newbuild-in-netherlands-8893831, both accessed 12 August 2022.

2161 - VVD, D66, CDA and ChristenUnie, "Omzien naar elkaar, vooruitkijken naar de toekomst - Coalitieakkoord 2021-2025", People's Party for Freedom and Democracy, Democrats 66, Christian Democratic Appeal and the Christian Union, 15 December 2021 (in Dutch), see https://www.parlement.com/9291000/d/pdfs/coalitieakkoord-2021-2025.pdf, accessed 12 July 2022.

Dutch newbuild plans took a new turn in December 2022, when it was announced that two reactors would be built near the Borssele plant with the government as co-investor. The plan is to begin construction in 2028 and complete it by 2035 thanks to an "accelerated approach".[2162] A second consultation issued by KPMG, tasked with identifying financing options for newbuild confirms that state involvement is indispensable and concluded that in the Dutch context existing financing schemes would have limited applicability. The KPMG study also stated that "market parties" also expect a role for the government to limit licensing and political risks and further agreements on setting up a decommissioning fund. Construction was estimated at 11 to 15 years, placing doubt on the "accelerated approach" envisioned by the Dutch Government.[2163] Meanwhile, Dutch company NRG Pallas, active in nuclear medicine and operator of the High Flux research reactor (HFR) at Petten, and Belgium nuclear engineering company Tractebel, subsidiary of utility Engie, signed a Memorandum of Understanding in March 2023 to "cooperate to support the new-build of nuclear power plants in the Netherlands".[2164] In June 2022, NRG Pallas had submitted a nuclear permit application for new medical isotope production and research reactor Pallas at Petten, Noord-Holland. Pallas is to replace the ageing HFR that has been operating since 1960. The construction license was granted in February 2023, prompting preparational construction work in April 2023.[2165]

On 12 April 2023, Minister for Climate and Energy Rob Jetten renewed his pledge to stick with the coalition agreement of 2021, despite disagreement from the "Expert Team Energy System 2050", which he had appointed to outline recommendations for the country's "Energy System Plan 2050". [2166] In its report, submitted on the same day as the Minister's remarks, the team sees "no or a limited role" for nuclear power in the Dutch energy system, and emphasized that new nuclear capacity would only be necessary if the Netherlands doubled or tripled their current electricity demand and European neighboring countries started importing electricity from the Netherlands. They further questioned the possibility of having a new reactor online before 2040, the potential choice of Borssele as a possible location for new capacity—as this could lead to system overload from the large amount of wind farms located nearby—all while noting that they had drawn their conclusion on nuclear power from other studies.[2167]

2162 - Bart Meijer, "Netherlands plans to build two nuclear power plants by 2035", *Reuters*, 9 December 2022, see https://www.reuters.com/business/energy/netherlands-plans-build-two-nuclear-power-plants-by-2035-2022-12-09/, and *NEI Magazine*, "Borssele preferred site for two new reactors", 15 December 2022, see https://www.neimagazine.com/news/newsbelgium-confirms-borssele-as-site-for-new-nuclear-plants-10439145/; both accessed 31 July 2023.

2163 - KPMG, "Onderzoek financieringsconstructies kernenergie", commissioned by the Ministry of Finances, Government of the Netherlands, 15 February 2023, see https://www.rijksoverheid.nl/documenten/rapporten/2023/02/15/onderzoek-financieringsconstructies-kernenergie, accessed 22 August 2023.

2164 - NRG, "Tractebel and NRG|PALLAS join forces to support nuclear new-build in the Netherlands", Press Release, 17 March 2023, see https://www.nrg.eu/en/news/tractebel-and-nrg-pallas-join-forces-to-support-nuclear-new-build-in-the-netherlands, accessed 7 November 2023.

2165 - NRG, "PALLAS receives nature permits", Press Release, 1 Match 2022, see https://www.nrg.eu/en/news/pallas-receives-nature-permits; and PALLAS, "First concrete pour construction pit PALLAS-reactor a fact", 4 May 2023, see https://www.pallasreactor.com/en/news/first-concrete-pour-construction-pit-pallas-reactor-a-fact/; also *WNN*, "Preparatory construction begins for Pallas research reactor", *World Nuclear News*, 5 May 2023, see https://world-nuclear-news.org/Articles/Construction-of-Pallas-research-reactor-under-way; all accessed 7 November 2023.

2166 - *NL Times*, "Cabinet moving forward with nuclear plant plans, despite experts seeing 'limited role'", 12 April 2023, see https://nltimes.nl/2023/04/12/cabinet-moving-forward-nuclear-plant-plans-despite-experts-seeing-limited-role; and Expertteam Energiesysteem 2050, "Energie door perspectief: rechtvaardig, robuust en duurzaam naar 2050", submitted 12 April 2023, see https://www.etes2050.nl/publicaties/outlookenergiesysteem2050/handlerdownloadfiles.ashx?idnv=2448181; both accessed 31 July 2023.

2167 - Expertteam Energisysteem 2050, "Energie door perspectief: rechtvaardig, robuust en duurzaam naar 2050", April 2023 (in Dutch), see https://etes2050.nl/publicaties/outlookenergiesysteem2050/HandlerDownloadFiles.ashx?idnv=2448181, accessed 22 August 2023.

Minister Jetten indicated that the "final decision" on new nuclear capacity would be made towards the end of 2024.[2168]

However, at the end of April 2023, the current administration stated its intent to reach a carbon neutral electricity system by 2035 with nuclear mentioned as a potential contributor of up to 10 percent of the mix if two new reactors were built. Emphasis on SMR technologies in the statement contradicts the assumption of just two plants providing such a large portion of electricity.[2169] Given the long lead time of nuclear newbuild in planning and construction experienced in other countries, it seems unlikely that the plans can be achieved.

In the same month, the Dutch new nuclear policy gained further momentum when approx. €320 million (US$349 million) were allocated to nuclear-associated funds in the draft document for the 2024 climate budget.[2170] These expenditures exceed the planned budget of the 2021 coalition agreement by €199 million (US$216.7 million). Included are €10 million (US$10.9 million) for studies spanning from 2023 to 2025 on lifetime extension at Borssele and additional €62 million (US$67.5 million) for the local municipality and the province of Zeeland for efforts regarding newbuild projects and continued operation at Borssele. Further €117 million (US$127.4 million) are allocated to feasibility studies regarding new nuclear power plant construction and €65 million (US$70.8 million) are to be spent on the development of knowledge and training of nuclear industry staff for the future operation of Dutch nuclear power plants.[2171] The draft was to be approved by the Dutch legislation before the summer of 2023. There has been no indication that this has been done, as parliamentary debate seemed to be still ongoing in July 2023[2172], while the Dutch Government has begun talking to "three potential and interested suppliers".[2173]

Additional €65 million (US$$_{2023}$71 million) are allocated for the development of SMRs in the Netherlands. In August 2022, Amsterdam-based ULC energy and British Rolls-Royce had signed an exclusive agreement to cooperate on Dutch SMR development. ULC hopes to apply for a license for its reactor in 2025, envisioning construction to begin in 2027.[2174] The previously mentioned July 2021 KPMG report had considered SMRs as an "interesting option" to market

2168 - *NL Times*, "Cabinet moving forward with nuclear plant plans, despite experts seeing 'limited role'", 12 April 2023, see https://nltimes.nl/2023/04/12/cabinet-moving-forward-nuclear-plant-plans-despite-experts-seeing-limited-role; and Expertteam Energiesysteem 2050, "Energie door perspectief: rechtvaardig, robuust en duurzaam naar 2050" submitted 12 April 2023, see https://www.etes2050.nl/publicaties/outlookenergiesysteem2050/handlerdownloadfiles.ashx?idnv=2448181; both accessed 31 July 2023.

2169 - Minister Rob A.A. Jetten, "Kamerbrief over voorjaarsbesluitvorming Klimaat", Ministry of Economic Affairs and Climate, addressed to the House of Representatives of the Netherlands (in Dutch), 26 April 2023, see https://www.rijksoverheid.nl/documenten/kamerstukken/2023/04/26/voorjaarsbesluitvorming-klimaat; and *WNN*, "Dutch government allocates funding for nuclear programme", *World Nuclear News*, 27 April 2023, see https://www.world-nuclear-news.org/Articles/Dutch-government-allocates-funding-for-nuclear-pro; both accessed 31 July 2023.

2170 - Government of the Netherlands, "Ontwerp Meerjarenprogramma Klimaatfonds 2024", Rijksoverheid, 26 April 2023, see https://www.rijksoverheid.nl/documenten/kamerstukken/2023/04/26/bijlage-2-ontwerp-meerjarenprogramma-klimaatfonds-2024, accessed 12 June 2023.

2171 - *WNN*, "Dutch government allocates funding for nuclear programme", *World Nuclear News*, 27 April 2023, see https://www.world-nuclear-news.org/Articles/Dutch-government-allocates-funding-for-nuclear-pro, accessed 12 June 2023.

2172 - Minister for Climate Policy and Energy, "Tijdelijke regels inzake de instelling van een Klimaatfonds (Tijdelijke wet Klimaatfonds)" addressed to the House of Representatives of The Netherlands (in Dutch), July 2023, see https://www.tweedekamer.nl/downloads/document?id=2023D30064, accessed 22 August 2023.

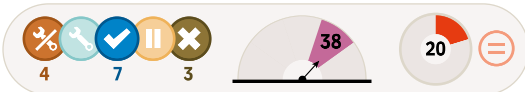
2173 - Charlotte van Campenhout, "Netherlands talking to three suppliers to build new nuclear power plants", *Reuters*, 29 June 2023, see https://www.reuters.com/business/energy/netherlands-talking-three-suppliers-build-new-nuclear-power-plants-2023-06-29/, accessed 22 August 2023.

2174 - Darrell Proctor, "Dutch Officials Set Funding for Nuclear Power Program", *POWER Magazine*, 1 June 2023, see https://www.powermag.com/dutch-officials-set-funding-for-nuclear-power-program/, accessed 12 June 2023.

parties but suggested waiting until "any FOAK problem is over" to identify successful projects, deeming the start of such a process impossible before 2027–2033.[2175]

Meanwhile, the share of renewable energies in gross electricity consumption is expected to increase from 33.4 percent in 2021 to 86.2 percent in 2030 and 95.5 percent in 2040 (contradicting envisioned nuclear plans). This development will be driven by the expansion of wind and solar power. The Dutch National Energy and Climate Plan envisions 28.3 GW of wind power capacity by 2040, of which 21.2 GW are planned as offshore capacity. Solar is expected to grow even faster as by 2040, 42.6 GW are to be installed.[2176] In the E.U., the Netherlands lead the charts on installed solar capacity per capita at 1.1 kW, followed by Germany (0.8 kW) and Belgium (0.6 kW).[2177]

Spain



As of 1 July 2023, Spain operates seven reactors with about 7 GW capacity that provided 56.15 TWh in 2022, compared to 54.22 TWh in 2021, representing 20.3 percent of the country's electricity generation—0.5 percentage less than last year's share and 18 percentage points below the historic maximum of 38.4 percent in 1989. Spain's reactors have a mean operating age of 38.4 years mid-2023.

Spanish nuclear ownership is concentrated in the utilities Iberdrola and Endesa. Both utilities have shared ownership with Naturgy at Almanaz-1 & -2, and with Naturgy and EDP at Trillo. Endesa is the sole owner of Asco-1, and Iberdrola fully owns Cofrentes. The two other plants, Asco-2 and Vandellos-2, have a shared ownership structure.[2178]

In January 2019, Spain's coalition government agreed a nuclear phase-out plan with utilities Endesa, Iberdrola and Naturgy as part of the overall Integrated National Energy and Climate Plan (INECP).[2179] All of Spain's reactors are expected to be closed by 2035; however, the policy also secured the possibility for all reactors to apply for lifetime extensions beyond 40 years, in contrast to previous governing Socialist Party's (PSOE) policy.[2180]

Asociación Nuclear Ascó-Vandellós II, known as ANAV, the operator of Vandellos-2, applied for a 10-year license renewal in 2019 for which it received approval in 2020.[2181] Under current

2175 - Karolin Schaps, "Netherlands has investor support for new nuclear plants", *Montel*, 8 July 2021, see https://www.montelnews.com/news/1237329/netherlands-has-investor-support-for-new-nuclear-plants, accessed 15 August 2022.

2176 - Ministry of Economic Affairs and Climate Policy, "Draft update of the National Plan Energy and Climate 2021-2030", Draft INEK Update, Automated Translation, Government of the Netherlands, June 2023, see https://commission.europa.eu/system/files/2023-07/EN_NETHERLANDS%20DRAFT%20UPDATED%20NECP.pdf, accessed 22 August 2023.

2177 - EurObservev'ER, "Photovoltaic barometer April 2023", May 2023, see https://www.eurobserv-er.org/photovoltaic-barometer-2023/, accessed 22 August 2023.

2178 - Foro Nuclear, "Nuclear power in Spain", Undated, see https://www.foronuclear.org/en/nuclear-power/nuclear-power-in-spain/, accessed 2 September 2023.

2179 - Carmen Monforte, "El Gobierno cierra el calendario con las fechas de clausura de cada central nuclear", *CincoDías*, *El País Economía*, 11 February 2019 (in Spanish), see https://cincodias.elpais.com/cincodias/2019/02/08/companias/1549647160_807281.html, accessed 8 July 2021.

2180 - *Público*, "La ministra Ribera afirma que es necesario prolongar la vida de las centrales nucleares", 3 March 2019 (in Spanish), see https://www.publico.es/politica/energia-nuclear-prolonga-vida-centrales-nucleares.html, accessed 8 July 2021.

2181 - *Platts Nuclear News Flashes*, "Operator of Spain's Vandellos-2 applies for 10-year license renewal", 28 March 2019.

planning, Vandellos-2 is scheduled to operate until 2034, offering the possibility to request an additional extension effective upon expiration of the current license in 2030.[2182]

The Cofrentes reactor, Spain's last operational BWR, was granted a license extension to 30 November 2030 in 2021.[2183]

CSN announced on 8 July 2021 that it had begun the analysis for the license renewal of the two PWRs at Ascó for nine and ten years respectively.[2184] Unit 1 was connected to the grid on 13 August 1983 and Unit 2 followed on 23 October 1985. Both reactors' licenses were extended in September 2021, allowing for the operation of Unit 1 to 2030 and Unit 2 to 2031.[2185]

The last reactor to apply for license renewal was Trillo. This plant is currently operating under a ten-year license valid until November 2024.[2186] In April 2023, an application for a ten-year license renewal was submitted to the regulator.[2187]

Spanish plans to end commercial operation of nuclear power plants are facing increasing opposition as the promotion of nuclear power as a necessary technology for a carbon neutral energy system in Spain has been gaining ground.[2188] If the planned closure of Almaraz I was to be stopped, all necessary licenses would have to be applied for by November 2024, three years prior to the scheduled closure. While some experts assume that this is not possible given the amount of necessary work,[2189] the snap elections called by current Prime Minister Pedro Sánchez for 23 July 2023 might affect the implementation of the phase-out policy.[2190] However, the election results were inconclusive and as of early September 2023 no new government was formed. Consequently, the phase-out policy remains in place for the time being.

2182 - CSN, "El Pleno del CSN informa favorablemente la solicitud de renovación de autorización de explotación de la central nuclear Vandellós II (Tarragona)", 24 June 2020 (in Spanish), see https://www.csn.es/-/el-pleno-del-csn-informa-favorablemente-la-solicitud-de-renovacion-de-autorizacion-de-explotacion-de-la-central-nuclear-vandellos-ii-tarragon-1, accessed 8 July 2021; and *Platts Nuclear News Flashes*, "Spain approves 10-year license extension for Vandellos-2 reactor", 25 June 2020.

2183 - *NEI Magazine*, "Spanish government approves renewal of operating licence for Cofrentes NPP", 23 March 2021, see https://www.neimagazine.com/news/newsspanish-government-approves-renewal-of-operating-licence-for-cofrentes-npp-8618722, accessed 25 March 2021.

2184 - CSN, "El CSN inicia el análisis de la solicitud de renovación de autorización de explotación de la central nuclear Ascó", Consejo de Seguridad Nuclear/Nuclear Safety Council, 8 July 2021 (in Spanish), see https://www.csn.es/en/noticias-csn/2021/-/asset_publisher/jMixvJv7q15q/content/el-csn-inicia-el-analisis-de-la-solicitud-de-renovacion-de-autorizacion-de-explotacion-de-la-central-nuclear-asco, accessed 8 July 2021.

2185 - ANAV, "anav 2022—energiía positiva", Asociación Nuclear Ascó-Vandellos II, 2022, see https://www.anav.es/app/uploads/2022/06/ANAV_MemoriaAnual2021.pdf, accessed 11 July 2022.

2186 - CNAT, "2021 CNAT Informe Ambiental", Centrales Nuclears Alamaraz-Trillo, May 2022 (in Spanish), see https://www.cnat.es/publipdf/Informe_Ambiental_2021_esp.pdf, accessed 11 July 2022.

2187 - David Dalton, "Trillo Nuclear Plant To Apply For 10-Year Operating Extension", *NucNet*, 4 April 2023, see https://www.nucnet.org/news/trillo-nuclear-plant-operator-to-apply-for-10-year-operating-extension-4-2-2023, accessed 5 September 2023.

2188 - *WNN*, "Nuclear plants vital for Spain, manifesto says", *World Nuclear News*, 10 March 2023, see https://www.world-nuclear-news.org/Articles/Nuclear-plants-vital-for-Spain,-manifesto-says, accessed 7 September 2023.

2189 - Laura Ojea, "El plan de cierre de nucleares no se puede cambiar aunque haya vuelco electoral en las próximas elecciones generals", *El Espanol* (in Spanish), 8 May 2023, see https://www.elespanol.com/invertia/empresas/energia/20230508/nucleares-no-cambiar-electoral-proximas-elecciones-generales/761923816_0.html, accessed 7 September 2023.

2190 - Pietro Lombardi, "Spain to vote on market reform, nuclear in Sunday's election", *Reuters*, 26 June 2023, see https://www.reuters.com/world/europe/spains-election-frontrunners-plan-u-turn-nuclear-power-phase-out-2023-06-26/; and Pablo Bronte, "Spain to vote on market reform, nuclear in Sunday's election", *Montel*, 20 July 2023, see https://www.montelnews.com/news/1511489/spain-to-vote-on-market-reform-nuclear-in-sundays-election; and Christina Martín, "Iberdrola, Endesa y Naturgy respiran: el 23-J será una segunda oportunidad para las nucleares" Hispanidad, 30 May 2023 (in Spanish), see https://www.hispanidad.com/economia/iberdrola-endesa-naturgy-respiran-23-j-sera-segunda-oportunidad-nucleares_12043069_102.html; all accessed 7 September 2023.

On 22 March 2019, Iberdrola confirmed an agreement had been reached for the extension of the Almaraz-1 and -2 reactors to operate until 2027 and 2028, respectively, instead of May 2021 and October 2023, and that it had applied for corresponding license extensions.2191 The agreement is based on the condition that Iberdrola will spend no more than €600 million (US$$_{2019}$677 million) during the remaining operational life of the reactors.[2192] In May 2020, the Spanish Nuclear Safety Council (El Consejo de Seguridad Nuclear or CSN) delivered a favorable report, then the license application received final Government approval in July 2020.[2193] This extended operational lifetimes of Almaraz-1 & -2, then 41 and 39 years old, respectively, to 1 November 2027 and 31 October 2028. The CSN approval sets various safety and compliance conditions, including the requirement, as noted above, for significant investment.[2194] The license of the units had already been extended by 10 years in 2010.[2195]

The Almaraz plant is located adjacent to the Tagus River in an area of significant seismic risk and 110 kilometers from the Portuguese border, resulting in strong opposition from stakeholders and the Government in Portugal.[2196] The latest dispute arose with the CSN May 2020 decision, prompting the Portuguese government to demand that Almaraz be subject to an environmental impact assessment (EIA).[2197] In July 2020, after the Spanish Government approved the plant's lifetime extension, the Pessoas-Animais-Natureza (PAN) party requested an investigation about potential violation under the Espoo convention,[2198] and filed a complaint with the United Nations Economic Commission for Europe (UNECE) in October 2020.[2199] In October 2022, the Committee reached the agreement to close the case, as no information gave

2191 - Iberdrola, "Iberdrola finalises the Almaraz renewal agreement, which guarantees economic activity and employment at the plant for the next 25 years", Press Release, 22 March 2019, see https://www.iberdrola.com/press-room/news/detail/iberdrola-finalises-almaraz-renewal-agreement-which-guarantees-economic-activity-employment-plant-next-years, accessed 8 July 2021.

2192 - Isla Binnie, "Power firms agree on route to close Spain's oldest nuclear plant", *Reuters*, 22 March 2019, see https://www.reuters.com/article/us-spain-energy-nuclearpower/power-firms-agree-on-route-to-close-spains-oldest-nuclear-plant-idUSKCN1R325G, accessed 8 July 2021.

2193 - Ministerio para la Transición Ecológica y el Reto Demográfico, "Orden TED-773-2020 , de 23 de julio, por la que concede la renovación de la autorización de explotación de la Central Nuclear de Almaraz, Unidades I y II", *Boletín Oficial del Estado*, Government of Spain (in Spanish), 6 August 2020, see https://www.csn.es/documents/10182/27922/Orden%20TED-773-2020%20,%20de%2023%20de%20julio,%20por%20la%20que%20concede%20la%20renovaci%C3%B3n%20de%20la%20autorizaci%C3%B3n%20de%20explotaci-%C3%B3n%20de%20la%20Central%20Nuclear%20de%20Almaraz,%20Unidades%20I%20y%20II, accessed 11 August 2020.

2194 - *elEleconomista*, "El CSN autoriza a la central nuclear de Almaraz a operar hasta octubre de 2028", 7 May 2020 (in Spanish), see https://www.eleconomista.es/empresas-finanzas/noticias/10529185/05/20/El-CSN-autoriza-a-la-central-nuclear-de-Almaraz-a-operar-hasta-octubre-de-2028.html, accessed 8 July 2021.

2195 - Boletin Oficial del Estado, "Orden ITC/158812010, de 7 de junio, por la que se concede renovación de la autorización de explotación a la Central Nuclear Almaraz, Unidades 1 y 11.", Ministerio de Industria, Turismo Y Comercio, Government of Spain, Num. 146, Sec. III, P. 51616 (in Spanish), 16 June 2010, see https://www.csn.es/documents/10182/27922/Orden%20ITC-1588-2010,%20de%207%20de%20junio,%20por%20la%20que%20se%20concede%20renovaci%C3%B3n%20de%20la%20autorizaci%C3%B3n%20de%20explotaci%C3%B3n%20a%20la%20Central%20Nuclear%20Almaraz,%20Unidades%20I%20y%20II, accessed 15 August 2022.

2196 - *Jornal Económico*, "Spanish nuclear power plant in Almaraz authorized to operate until 2028", 8 May 2020, see https://jornaleconomico.sapo.pt/en/news/Spanish-nuclear-power-plant-in-Almaraz-authorized-to-operate-until-2028-586165, accessed 8 July 2021.

2197 - *LUSA*, "Governo quer que extensão de funcionamento de Almaraz seja avaliada", as published in *Notícias ao Minuto,* 5 May 2020 (in Portuguese), see https://www.noticiasaominuto.com/pais/1483078/governo-quer-que-extensao-de-funcionamento-de-almaraz-seja-avaliada, accessed 8 July 2021

2198 - *Portugal Resident*, "Almaraz nuclear risks: PAN lodges complaint against Spain to UN", 30 July 2020, see https://www.portugalresident.com/almaraz-nuclear-risks-pan-lodges-complaint-against-spain-to-un/, accessed 7 July 2021; and Implementation Committee, "EIA/IC/INFO/34—Correspondence as a result of information provided to the Committee from other sources", United Nations Economic Commission for Europe, 30 July 2020, see https://unece.org/eiaicinfo34; accessed 18 August 2022.

2199 - André Silva, "Non-compliance of the Espoo Convention by the Member State Spain", PAN, addressed to the Implementation Committee, Convention on Environmental Impact Assessment in a Transboundary Context, UNECE, United Nations, 9 October 2020, see https://unece.org/DAM/env/pp/compliance/C2020-183_Spain/Att1_Complaint_to_Espoo_Convention_Imp_Committee.pdf, accessed 18 August 2022.

rise to a "profound suspicion of non-compliance by Spain" or indicated "major change" at the site.[2200] However, as of early September 2023, the case was still categorized as "pending" on the UNECE website.[2201]

In order to limit the impact of high energy prices on households, Spain introduced windfall profit tax of 1.2 percent on power utilities' sales in 2023 and 2024.[2202] In its 2022-Annual Report, industry lobby group Foro Nuclear "insists that the economic viability of Spanish nuclear reactors be guaranteed for as long as they remain in operation."[2203]

In 2016, the Australian mining company Berkeley Energia began infrastructure work in the western region of Salamanca to develop a large uranium mining area. Local authorities have since granted land use permits, but the Spanish Ministry for Ecological Transition and Demographic Challenge (MITECO) dismissed the application to construct a uranium processing plant in late 2021.[2204] Berkeley's administrative appeal was rejected in February 2023, with the Spanish authorities highlighting CSN's 2021-assessment of "poor reliability and high uncertainty of the safety analyses of the radioactive site." Berkeley still claims that the procedure is illegal due to infringement of regulations on administrative proceedings and the so-called "Energy Charter Treaty".[2205] The company filed an investment dispute notice with the Government to initiate international arbitration, but "remains hopeful that the dispute can be resolved amicably through prompt negotiations."[2206]

In July 2023, the country submitted a 580-page draft of its updated INECP aligned with E.U. legislation setting more ambitious emission reduction targets.[2207] The proposed plan expects 214 GW of installed power capacity by 2030, including 160 GW of renewables and 22 GW of storage, while maintaining its projection of 3 GW of nuclear power, reducing its contribution in overall installed capacity to 1.4 percent. Further indicative technology distribution entails 76 GW of solar PV (of which 19 GW is small-scale auto-consumption), 62 GW of wind, 26.6 GW in combined cycle gas and 14.5 GW of hydro.

2200 - UNECE, "Report of the Implementation Committee on its fifty-fourth session", ECE/MP.EIA/IC/2022/7, Implementation Committee, Meeting of the Parties to the Convention on Environmental Impact Assessment in a Transboundary Context serving as the Meeting of the Parties to the Protocol on Strategic Environmental Assessment, Implementation Committee, United Nations, 21 October 2022, see https://unece.org/sites/default/files/2022-11/ece_mp.eia_ic_2022_7_advance_edited.pdf, accessed 5 September 2023.

2201 - UNECE, "ACCC/C/2020/183 Spain", Undated, see https://unece.org/env/pp/cc/accc.c.2020.183_spain, accessed 5 September 2023.

2202 - Belén Carreño, "Spain seeks to set nuclear, hydro power prices to curb profits", *Reuters*, 10 January 2023, see https://www.reuters.com/business/energy/spain-seeks-set-nuclear-hydro-prices-end-windfall-profits-2023-01-10/; and *Montel*, "Spain approves 1.2% windfall tax on energy companies", 22 December 2022, see https://www.montelnews.com/news/1391799/spain-approves-12-windfall-tax-on-energy-companies; both accessed 4 September 2023.

2203 - Foro Nuclear, "Nuclear Results in 2022 and Future Perspectives—Executive Summary", April 2023, see https://www.foronuclear.org/wp-content/uploads/2023/04/Nuclear-results-in-2022-executive-summary.pdf?x67659, accessed 4 September 2023.

2204 - *WNN*, "Spanish uranium project denied authorisation", *World Nuclear News*, 29 November 2021, see https://www.world-nuclear-news.org/Articles/Spanish-uranium-project-denied-authorisation, accessed 7 September 2023.

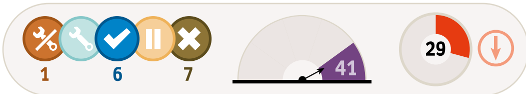
2205 - Inti Landauro and Emma Pinedo, "Spain sticks with decision to block Berkeley uranium mine", *Reuters*, 7 February 2023, see https://www.reuters.com/markets/commodities/spain-sticks-with-decision-block-berkeleys-uranium-mine-2023-02-07/, accessed 7 September 2023.

2206 - Berkeley Energia Limited, "Permitting update", News Release, 7 February 2023, see https://polaris.brighterir.com/public/berkeley_energia/news/rns/story/rnkovpr, accessed 7 September 2023.

2207 - Government of Spain, "Draft Update of the Plan Integrated National Energy and Climate 2023-2030", European Commission, July 2023, see https://commission.europa.eu/system/files/2023-07/EN_SPAIN%20DRAFT%20UPDATED%20NECP.pdf, accessed 4 September 2023.

By comparison, according to the "Statistical Review of World Energy", solar and wind combined delivered 35 percent of Spain's electricity in 2022, with 30.4 percent of natural gas, about 20 percent nuclear power, 6.2 percent hydro, 3.5 percent of oil and 3.2 percent of coal. Power generation from renewable energies could exceed 50 percent in 2023, according to the national grid operator Red Eléctrica de España and various observers.[2208] The country's 2050 objectives stipulate renewables to deliver an ambitious 100 percent of electricity production and 97 percent of final energy consumption.[2209]

Sweden



Sweden's nuclear fleet of six reactors generated 50 TWh in 2022, a 2.7 percent decrease over the previous year, which represented 29.4 percent of the country's total electricity production. Nuclear power's share in the country's electricity generation mix peaked in 1996 at 52.4 percent when 12 reactors were operating, while the fleet reached its highest output in 2004 at over 75 TWh with 11 units still on the grid.

The 1100-MW reactor Ringhals-4 was taken off the grid for routine maintenance work in August 2022. During tests, the reactor pressure vessel was damaged, pushing the restart back to November 2022 as Vattenfall had to first build a mock-up to train staff and test procedures and equipment for the repair of damaged components.[2210] This replacement work has proven to be more complex than initially imagined, prompting Vattenfall to push the restart date first to January, then February and finally March 2023.[2211] However, in late March, start-up activities were interrupted by leakage "from a small valve in a chemical sampling tube" adjacent to the reactor. The unit eventually came back online at full capacity on 12 April 2023.[2212]

For more than four decades, planned phaseout was a central part of nuclear policy in Sweden. A 1980 public referendum set the target to end commercial utilization of nuclear power by 2010. Sweden retained the 2010 phaseout date until the middle of the 1990s, but an active debate on the country's nuclear future continued and led to a new inter-party deal to start the phaseout earlier but abandon the 2010 deadline. The first commercial reactors to close were Barsebäck-1 in 1999 and Barsebäck-2 in 2005. In June 2010, the parliament voted by a tight margin to abandon the phaseout legislation and aim for carbon neutrality by 2050. Following

2208 - Red Eléctrica, "Renewable energy could account for 50% of Spain's electricity generation mix in 2023", Press Release, 23 March 2023, see https://www.ree.es/en/press-office/news/press-release/2023/03/renewable-energy-could-account-for-50percent-of-spains-electricity-generation-mix-in-2023; and Jessica Casey, "Rystad: Spain's renewable power generation to top 50% in 2023", *Energy Global*, 12 June 2023, see https://www.energyglobal.com/special-reports/12062023/rystad-spains-renewable-power-generation-to-top-50-in-2023/; both accessed 12 June 2023.

2209 - Government of Spain, "España 2050: Fundamentos y propuestas para una Estrategia Nacional de Largo Plazo", May 2021 (in Spanish), see https://www.lamoncloa.gob.es/presidente/actividades/Documents/2021/200521-Estrategia_Espana_2050.pdf; and EIA, "Spain 2021—Energy Policy Review", International Energy Agency, May 2021, see https://iea.blob.core.windows.net/assets/2f405ae0-4617-4e16-884c-7956d1945f64/Spain2021.pdf, accessed 16 August 2022.

2210 - Nora Buli, Anna Ringstrom and Anne Kauranen, "Sweden's Ringhals 4 nuclear outage extends into winter months", *Reuters*, 13 September 2022, see https://www.reuters.com/business/energy/swedens-ringhals-4-nuclear-outage-extends-into-winter-months-2022-09-13/, accessed 8 September 2023.

2211 - *NEI Magazine*, "Restart of Ringhals 4 faces further delay", *Nuclear Engineering International*, 28 March 2023, see https://www.neimagazine.com/news/newsrestart-of-ringhals-4-faces-further-delay-10708332, accessed 8 September 2023.

2212 - Vattenfall, "Ringhals 4 åter i full produktion", Press Release (in Swedish), 12 April 2023, see https://group.vattenfall.com/se/nyheter-och-press/nyheter/2023/ringhals-4-ater-i-full-produktion, accessed 8 September 2023.

this decision, new reactors were allowed to be built, but only at pre-existing sites.[2213] Since then, the goal of carbon-neutrality has been pulled forward to 2045,[2214] with the goal of a "renewable" electricity system by 2040, explicitly stressing that this does not automatically correspond to nuclear phaseout.[2215]

Sweden's new center-right government (Moderate Party, Christian Democrats and Liberal Party) in their coalition agreement of 14 October 2022 with the far-right (Sweden Democrats)—referred to as the Tidö Agreement—pledges to change the energy policy goal "from 100% renewable to 100% fossil-free", paving the way for the inclusion of nuclear power. The new government indicated it would also provide special credit guarantees for nuclear power investments totaling SEK400 billion (US$$_{2022}$35.7 billion).[2216] While presenting the newly agreed Government Policy to Parliament in October 2022, Prime Minister Ulf Kristersson stated:

> At a later date, the Government will propose credit guarantees for new construction of Swedish nuclear power plants, alongside legislative amendments to enable new nuclear power production via shorter permit processes and administrative fast tracks, for example. The prohibition of new reactors in new locations and of more than ten simultaneously active reactors will be removed from the Swedish Environmental Code. Vattenfall will receive owner directives to commence planning and procurement of new Swedish nuclear power facilities.[2217]

Accordingly, the government is pushing to scrap existing rules that limit total number of reactors to ten and introduce legislation allowing new capacity to be installed at other sites than existing nuclear power plants. These various legislative proposals—which were subject to consultation until April 2023—are envisioned to become effective by March 2024.[2218]

Meanwhile, in June 2023, Parliament approved the rewording of Sweden's 2040-electricity targets, now aiming for "100% fossil-free" instead of "100% renewables",[2219] and in July 2023, the government submitted to the European Commission the draft of its updated National

2213 - WNA, "Nuclear Power in Sweden", World Nuclear Association, Updated July 2023, see https://world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx, accessed 9 September 2023.

2214 - Ministry of the Environment and Energy, "The Swedish climate policy framework", Government Offices of Sweden, 2017, see https://www.government.se/495f60/contentassets/883ae8e123bc4e42aa8d59296ebe0478/the-swedish-climate-policy-framework.pdf, accessed 14 July 2022.

2215 - Ministry of Infrastructure, "Sweden's Integrated National Energy and Climate Plan", Regeringen, Government of Sweden, 16 January 2020, see https://energy.ec.europa.eu/system/files/2020-03/se_final_necp_main_en_0.pdf, accessed 8 September 2023.

2216 - *WNN*, "New Swedish government seeks expansion of nuclear energy", *World Nuclear News*, 17 October 2022, see https://www.world-nuclear-news.org/Articles/New-Swedish-government-seeks-expansion-of-nuclear?feed=feed, accessed 17 October 2022.

2217 - Prime Minister Ulf Kristersson, "Statement of Government Policy", before the Riksdag/Parliament of Sweden, Government of Sweden, 18 October 2022, see https://www.government.se/speeches/2022/10/statement-of-government-policy/, accessed 8 September 2023.

2218 - Regeringskansliet, "Regeringen föreslår ändrad lagstiftning om kärnkraften", Press Release (in Swedish), Government Offices of Sweden, 11 January 2023, see https://www.regeringen.se/pressmeddelanden/2023/01/regeringen-foreslar-andrad-lagstiftning-om-karnkraften/; and Niklas Pollard and Anna Ringstrom, "Sweden makes regulatory push to allow new nuclear reactors", *Reuters*, 11 January 2023, see https://www.reuters.com/world/europe/sweden-makes-regulatory-push-allow-new-nuclear-reactors-2023-01-11/, accessed 12 January 2023.

2219 - Simon Johnson, "Swedish parliament passes new energy target, easing way for new nuclear power", *Reuters*, 20 June 2023, see https://www.reuters.com/sustainability/climate-energy/swedish-parliament-passes-new-energy-target-easing-way-new-nuclear-power-2023-06-20/, accessed 8 September 2023.

Energy and Climate Plan (to be finalized by June 2024), which consecrates the newly adopted formulation.[2220]

The Government tasked the Swedish Radiation Safety Authority (SSM) to investigate "how laws, regulations and other measures can be developed for existing and future nuclear power" upon which SSM published two reports in February[2221] and August 2023[2222]. The first report concluded that "there is a legal framework and other prerequisites in place for further operation of the existing nuclear power plants as long as the facilities are safe." The second report contained various proposals, including:

- Removed restrictions on the maximum number of permitted reactors in operation, as well as equal conditions for different types of energy sources regarding possible siting and municipal veto, through changes in the environmental code.
- Enhanced flexibility in the legal framework for different reactor technologies and new deployment and operational models.
- Clarification and simplification of the licensing process, e.g. by removing double application of the environmental code.
- Extended and clarified mandate for the Swedish Radiation Safety Authority's to decide on permits and regulations.
- Increased international cooperation and opportunities for knowledge developing about new reactor technologies, for example by introducing a pre-licensing review process.[2223]

In June 2022, Vattenfall had launched a feasibility study on the commercial, legal and technological prerequisites to build at least two SMRs at Ringhals, to be followed by a public consultation process,[2224] and notified the grid operator in December 2022 on the possibility of connecting 2.8 GW of new capacity at Ringhals in 2032.[2225] The decision whether to proceed further is to be based on the outcome of the feasibility study which the company expects to complete by December 2023.[2226] Per latest announcements, the company assumes that "a

2220 - Ministry of Climate and Industry, "Draft updated National Energy and Climate Plan (NECP) for Sweden", Government Offices of Sweden, 11 July 2023, see https://commission.europa.eu/publications/sweden-draft-updated-necp-2021-2030_en, accessed 9 September 2023.

2221 - SSM, "Utveckling av regelverk och andra åtgärder för befintlig och framtida kärnkraft (delredovisning)", Strålsäkerhetsmyndigheten/Swedish Radiation Safety Authority, submitted to Ministry of Climate and Industry (in Swedish), 28 February 2023, see https://www.stralsakerhetsmyndigheten.se/globalassets/regeringsuppdrag/rapporter-2023/rapport-utveckling-av-regelverk-och-andra-atgarder-for-befintlig-och-framtida-karnkraft.pdf, accessed 9 September 2023.

2222 - SSM, "Utveckling av regelverk och andra åtgärder för befintlig och framtida kärnkraft (slutredovisning)", Strålsäkerhetsmyndigheten/Swedish Radiation Safety Authority, 8 August 2023 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/contentassets/4c2815f4ad27442783073a6e1948a631/ssm2022-6007-7-utveckling-av-regelverk-och-andra-atgarder-for-befintlig-och-framtida-karnkraft.pdf, accessed 9 September 2023.

2223 - SSM, "Swedish Radiation Safety Authority submits proposals for existing and future nuclear power", News Release, Strålsäkerhetsmyndigheten/Swedish Radiation Safety Authority, 9 August 2023, see https://www.stralsakerhetsmyndigheten.se/en/press/news/2023/swedish-radiation-safety-authority-submits-proposals-for-existing-and-future-nuclear-power/, accessed 8 September 2023.

2224 - Vattenfall, "Vattenfall begins feasibility study on construction of small modular reactors at Ringhals", Press Release, 28 June 2022, see https://group.vattenfall.com/press-and-media/pressreleases/2022/vattenfall-begins-pilot-study-on-construction-of-small-modular-reactors-at-ringhals, accessed 8 September 2023.

2225 - Nora Buli, "Sweden's Vattenfall investigates new 2.8 GW nuclear capacity at Ringhals", *Reuters*, 25 January 2023, see https://www.reuters.com/business/energy/swedens-vattenfall-plans-new-28-gw-nuclear-reactors-ringhals-2023-01-25/, accessed 8 September 2023.

2226 - Vattenfall, "Nuclear Power—Vattenfall's SMR feasibility study at Ringhals – 'Nucelerate West'", Undated, see https://group.vattenfall.com/what-we-do/our-energy-sources/nuclear-power/smr-at-ringhals, accessed 8 September 2023.

first reactor could be operational at the beginning of or mid-2030s."[2227] The Finnish company Fortum that operates the Loviisa plant in Finland, also launched a two-year feasibility study in October 2022 for the deployment of new nuclear—including SMRs—in both Finland and Sweden (see Annex 1 – Finland).[2228]

In August 2023, Michael Lewis, CEO of Uniper, co-owner of all three currently operating nuclear power plants, reiterated that his company would "not invest any further in nuclear power" but rather in "new flexible capacities like batteries and gas plants that can be converted to being zero carbon". Uniper is planning to leave coal and boost its non-fossil, low-carbon options from just 20 percent currently to 80 percent by 2030 and become carbon neutral by 2040.[2229]

Swedish Prime Minister Ulf Kristersson visited Paris in January 2023 and reiterated that the "new Swedish government is determined to build new nuclear power plants" and stated that he was "entirely open to France being one of the countries that will make sure that Sweden has more nuclear power".[2230] The subject was also on the agenda in May 2023 when South Korean Prime Minister Han Duck-soo visited his Swedish counterpart, who promised that "Sweden is going to build new nuclear power plants" and explained "South Korea is a role model when it comes to developing new nuclear energy, and we are now enhancing our cooperation."[2231]

In early August 2023, Environment Minister Romina Pourmokhtari had announced that, until 2045, Sweden would add nuclear capacity corresponding to "at least ten new conventional reactors". A few days later, the corresponding press release had disappeared from the Government website. Answering a parliamentary question to the effect, Pourmokhtari stated that the press release "could be misinterpreted as the government committing to a certain number of new reactors. It is too early to say exactly what the electricity mix will look like in the future."

With electricity prices under pressure resulting from the energy crisis caused by Russia's invasion of Ukraine, Vattenfall was asked by the new government to investigate whether recently closed reactors Ringhals-1 and -2 could be restarted.[2232] This option was swiftly declined by Torbjörn Wahlborg, Vattenfall's Head of Electricity Production, as it would be "risky, costly and perhaps not even possible." Wahlborg further indicated that even if carried out, the restart would offer no relief on electricity prices in the 2020s, as the restart of

2227 - Vattenfall, "Small nuclear reactors, the next big thing", Press Release, 29 August 2023, see https://group.vattenfall.com/press-and-media/newsroom/2023/small-nuclear-reactors-the-next-big-thing, accessed 9 September 2023.

2228 - Fortum, "Fortum and Kärnfull Next to jointly explore opportunities in Sweden for Small Modular Reactors", Press Release, 15 December 2022, see https://www.fortum.com/media/2022/12/fortum-and-karnfull-next-jointly-explore-opportunities-sweden-small-modular-reactors; and *NEI Magazine*, "Sweden's Kärnfull Next and GE Hitachi to collaborate on SMRs", 17 March 2022, see https://www.neimagazine.com/news/newsswedens-krnfull-next-and-ge-hitachi-to-collaborate-on-smrs-9558738/, accessed 9 September 2023.

2229 - Charles Szumski, "Germany refuses to build nuclear Uniper plant in Sweden ", *Euractiv*, 11 November 2022, see https://www.euractiv.com/section/politics/news/germany-refuses-to-build-nuclear-uniper-plant-in-sweden/; and Nathan Witkop, "Uniper to avoid new investment in nuclear power – CEO", *Montel*, 1 August 2023, see https://www.montelnews.com/news/1513409/uniper-to-avoid-new-investment-in-nuclear-power--ceo; both accessed 9 September 2023.

2230 - *Euronews* and *AFP*, "Sweden turns to France as it looks to buy two new nuclear reactors", 3 January 2023, see https://www.euronews.com/2023/01/03/sweden-turns-to-france-as-it-looks-to-buy-two-new-nuclear-reactors, accessed 9 September 2023.

2231 - Prime Minister's Office, "New nuclear energy in focus when Prime Minister received South Korea's Prime Minister", Press Release, Government Offices of Sweden, 10 May 2023, see https://www.government.se/articles/2023/05/new-nuclear-energy-in-focus-when-prime-minister-receives-south-koreas-prime-minister/, accessed 8 September 2023.

2232 - *WNN*, "New Swedish Government Seeks Expansion of Nuclear Energy", 17 October 2022, op. cit.

Ringhals-1 alone would take at least six or seven years and cost "many billions [SEK]"[2233], while the restart of Ringhals-2 was not possible at all due to the damaged bottom plate of the reactor tank. Wahlborg further stresses that Sweden should instead focus on operating capacities and pave the way for new nuclear capacities.[2234]

Despite the postponement of the nuclear phaseout, several reactors have closed in the past decade for economic reasons. In 2015, operators decided to close the country's four oldest reactors.[2235] Consequently, Unit 2 at Oskarshamn, which last produced electricity in 2013, was officially closed in January 2016, followed by Unit 1 in June 2017, then Ringhals-2 in December 2019, and Ringhals-1 in 2020. First grid connection for these units occurred in 1974, with the exception of Oskarshamn-1, which started up in 1971.[2236] Decommissioning work is underway at both sites (see Decommissioning Status Report).

Six reactors, half of the original fleet, are thus still in operation at Forsmark, Oskarshamn and Ringhals. It is planned to operate each reactor for a full 60 years, resulting in the youngest reactors, Forsmark-3 and Oskarshamn-3, to be closed potentially as late as 2045.[2237]

To operate reactors into the 2040s, owners need to win approval following ten-year periodic safety reviews. The first to do so were the 39-year-old Forsmark-1 and 38-year-old Forsmark-2, which secured SSM approval on 18 June 2019 to operate for 10 more years until 2028.[2238] SSM approved continued operation for the reactors, while also finding

> deficiencies regarding the containment and aging of concrete structures deemed as small in the current situation, but it may increase in the long term if the deficiencies are not remedied since serious degradations […] may occur in the reactor containment and other building structures of importance for radiation safety.[2239]

This could mean significant refurbishment work will be required in the coming years.

Major upgrading work at all of Sweden's reactors was completed in 2020. This relates to the SSM requirement that all reactors operating beyond 2020 have Independent Core Cooling Systems (ICCS) designed to withstand extreme external hazards. The new system obligation

2233 - SEK1 ≈ US$0.09 (as of July 2023)

2234 - Torbjörn Wahlborg, "Debatt: Inte rimligt att återstarta reaktor vid Ringhals", *Dagens Industri*, 18 March 2023 (in Swedish), see https://www.di.se/debatt/debatt-inte-rimligt-att-aterstarta-reaktor-vid-ringhals/, accessed 9 September 2023.

2235 - OKG, "Decision Made Regarding Premature Shutdown of Units Oskarshamn 1 and Oskarshamn 2", Press Release, Oskarshamns Kraftgrupp, 14 October 2015, see https://www.okg.se/en/press-room/decision-made-regarding-premature-shutdown-of-units-oskarshamn-1-and-oskarshamn-2; and Vattenfall, "Vattenfall changes direction for operational lifetimes of Ringhals 1 and 2", 28 April 2015, Press Release, see https://group.vattenfall.com/press-and-media/pressreleases/2015/vattenfall-changes-direction-for-operational-lifetimes-of-ringhals-1-and-2; both accessed 31 August 2022.

2236 - SKB, "Plan 2019 - Costs from and including 2021 for the radioactive residual products from nuclear power - Basis for fees and guarantees for the period 2021-2023", Svensk Kärnbränslehantering/Swedish Nuclear Fuel and Waste Management Company, December 2019, see https://www.skb.com/publication/2494604/TR-19-26.pdf; and Vattenfall, "The Ringhals 1 reactor has crossed the finish line", Press Release, 2021, see https://group.vattenfall.com/press-and-media/newsroom/2021/the-ringhals-1-reactor-has-crossed-the-finish-line, both accessed 14 July 2022.

2237 - WNA, "Nuclear Power in Sweden", World Nuclear Association, Updated July 2023, see https://world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx, accessed 14 September 2023.

2238 - SSM, "Forsmark har förutsättningar att fortsätta driva F1 och F2 strålsäkert till 2028s", Press Release (in Swedish), Strålsäkerhetsmyndigheten/Swedish Radiation Safety Authority, 24 June 2019.

2239 - SSM, "Återkommande helhetsbedömning—Forsmarks Kraftgrupp AB—Forsmark 1 och 2", Strålsäkerhetsmyndigheten/Swedish Radiation Safety Authority, 18 June 2019 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/contentassets/6b998f90ef4c4dda8a5914ce3c3ca982/granskning-av-aterkommande-helhetsbedomning-av-forsmark-1-och-2.pdf, accessed 9 September 2023.

is a consequence of the stress tests results carried out following the Fukushima disaster in 2011.[2240] On 18 December 2020, SSM confirmed that the six reactors predominantly meet set conditions and requirements.[2241] Further modernization of components at Ringhals-3 and -4 will be conducted by Framatome that in May 2023 was contracted by Vattenfall to update reactor control systems as well as refurbish reactor coolant pumps. This work is to commence in 2026 at Unit 3 and 2027 at Unit 4.[2242]

In the past, due to historical nuclear phaseout plans and the current limitation of nuclear new build to existing sites, the replacement of old reactors, the Swedish strategy has focused on uprating existing reactors.[2243] For example, at Forsmark, this has been ongoing since the 1980s and, according to IAEA-PRIS data, consecutive uprating has increased installed capacity of the three units respectively by 15.6 percent, 24.6 percent, and 11.6 percent. Further plans include to uprate Unit 1 by another 100 MW[2244] and Forsmark-3 by further 200 MW.[2245] In total, this strategy has, as of September 2023, led to 992 MW of additional nuclear capacity in operational nuclear power plants.[2246]

In 2022, 161 TWh of electricity (net) were produced by mainly hydro (43 percent), nuclear (31 percent), and onshore wind (20 percent), the remainder being generated from fossil fuel sources.[2247] Solar PV generation has been increasing over the past few years but remains small with 2.3 TWh in 2022 representing just 1.4 percent.[2248] While the target of a fully decarbonized electricity system by 2040 remains, amendments to the legislation (mentioned above) might potentially include nuclear new build instead of full reliance on renewables.

2240 - Ministry of the Environment, "Sweden's Eighth National Report under the Convention on Nuclear Safety—Sweden's Implementation of the Obligations of the Convention", Swedish Government, Ds 2019:16, August 2019 see https://www.regeringen.se/contentassets/c8c431c94efb4c4abefb38ca36272b5a/swedens-eighth-national-report-under-the-convention-on-nuclear-safety-ds-201916.pdf, accessed 9 September 2023.

2241 - SSM, "Forsmark, Ringhals och OKG uppfyller kraven på oberoende härdkylning", Strålsäkerhetsmyndigheten/Swedish Radiation Safety Authority, 18 December 2020 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/press/nyheter/2020/forsmark-ringhals-och-okg-uppfyller-kraven-pa-oberoende-hardkylning/, accessed 15 July 2021.

2242 - Framatome, "Framatome signs contract with Vattenfall to modernize reactor systems at Ringhals", Press Release, 10 May 2023, see https://www.framatome.com/medias/framatome-signs-contract-with-vattenfall-to-modernize-reactor-systems-at-ringhals/, accessed 9 September 2023.

2243 - WNA, "Nuclear Power in Sweden", World Nuclear Association, Updated July 2023, op. cit.

2244 - Roger Fry, "Vattenfall plans 100 MW upgrade to Forsmark 1 reactor", *Montel*, 13 June 2022, see https://www.montelnews.com/news/1327678/vattenfall-plans-100-mw-upgrade-to-forsmark-1-reactor; and *NEI Magazine*, "Vattenfall to increase power at Forsmark NPP unit 1", 16 June 2022, see https://www.neimagazine.com/news/newsvattenfall-to-increase-power-at-forsmark-npp-unit-1-9777570, accessed 9 September 2023.

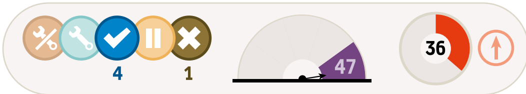
2245 - *NEI Magazine*, "Restart of Ringhals 4 faces further delay", 28 March 2023, op. cit.

2246 - IAEA, "Country Statistics Sweden", Updated 13 September 2023, see https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=SE, accessed 14 September 2023.

2247 - Fraunhofer ISE, "Public net electricity generation in Sweden in 2022", *Energy-Charts*, with data from ENTSO-E, 13 September 2023, see https://energy-charts.info/charts/energy_pie/chart.htm?l=en&c=SE&year=2022&interval=year, accessed 14 September 2023.

2248 - Ember, "European Union | Electricity Transition—Sweden electricity generation by source", Updated April 2023, see https://ember-climate.org/countries-and-regions/regions/european-union/, accessed 14 September 2023.

Switzerland



After declining for two years to just 18.5 TWh nuclear electricity generation in 2021, the lowest level since the early 1980s, Swiss nuclear power plants generated 23.1 TWh (+27,4 percent) in 2022, raising the share of nuclear electricity generation to 36.4 percent, compared to the historic maximum of 44.4 percent in 1996.[2249]

With an average age of 47.3 years (see Figure 80), Switzerland operates the second oldest nuclear fleet in the world behind the Netherlands (that operates only one 50-year old unit), of which Beznau-1, age 54, is the oldest commercially operating reactor in the world. Beznau-2 is almost 52 years old. The safety assessment of the old plant remains controversial. The Swiss Federal Nuclear Safety Inspectorate (ENSI) in November 2021 concluded in a 404-page safety assessment report covering the evaluation period 2012–2016 that some improvements were needed in the "assessment and maintenance of the quality" of the spent fuel pools and increased ageing surveillance of certain components. The report included a list of over 30 required measures established by ENSI to be implemented with individually specified timelines, starting in 2022 with the last item to be completed by the end of 2024.[2250]

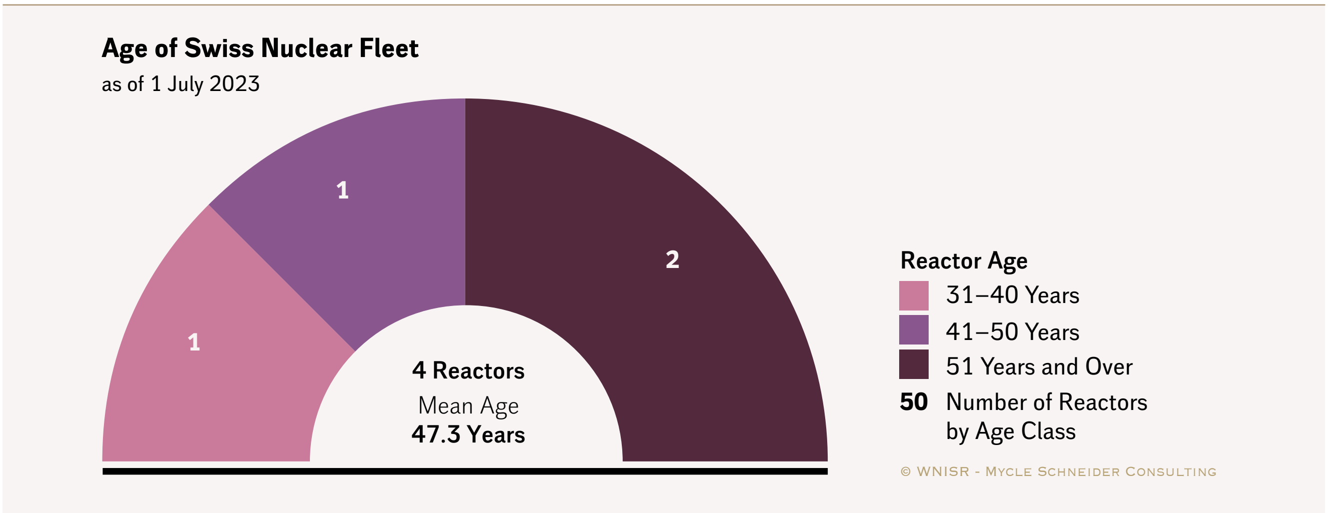
An independent study completed in February 2022 evaluated the 2015 AREVA "fractographic investigation", forming the basis for the operator's conclusion that any defaults at the reactor pressure vessel of Beznau-1—already subject to a series of contradictory evaluations in the past (see previous WNISR editions)—were non-evolutive. The expertise concluded that the AREVA analysis provides "only a superficial exemplary examination of different microstructural features" and appears to be "incomplete".[2251]

2249 - BFE/OFEN, "Schweizerische Elektrizitätsstatistik 2022 / Statistique suisse de l'électricité 2022", Bundesamt für Energie/Office fédérale de l'énergie/Swiss Federal Office of Energy (in German and French), June 2023, see https://pubdb.bfe.admin.ch/de/publication/download/11425; and BFE/OFEN, "Schweizerische Elektrizitätsstatistik 2021 / Statistique suisse de l'électricité 2021", June 2022 (in German and French), see https://pubdb.bfe.admin.ch/fr/publication/download/10942; both accessed 10 September 2023.

2250 - ENSI/IFSN, "Sicherheitstechnische Stellungnahme zur Periodischen Sicherheitsüberprüfung 2017 des Kernkraftwerks Beznau", ENSI 14/3025 (in German), Eidgenössisches Nuklearsicherheitsinspektorat/Swiss Federal Nuclear Safety Inspectorate, 16 November 2021, see https://www.ensi.ch/de/dokumente/sicherheitstechnische-stellungnahme-zur-periodischen-sicherheitsueberpruefung-2017-des-kernkraftwerks-beznau/, accessed 20 August 2022.

2251 - Kim Wallin, "Assessment of Fractographic Investigation Report and Applicability of the Master Curve Method", kw-solutions, commissioned by Schweizerische Energiestiftung/Swiss Energy Foundation, 14 February 2022, see https://energiestiftung.ch/files/energiestiftung/Studien/2022_Wallin_RDB/KW-2022-01.pdf, accessed 10 September 2023.

Figure 80 · Age Distribution of the Swiss Nuclear Fleet



Source: WNISR with IAEA-PRIS, 2023

Another independent report on the Leibstadt plant listed numerous deficiencies of the safety standards including insufficient protection against airplane crashes and the penetration of the concrete foundation in case of a core-melt accident. The assessment concludes that a lifetime extension would not be feasible under current safety standards as certain critical components could not be replaced or appropriately backfitted.[2252] Leibstadt will reach its design lifetime of 40 years in May 2024.

In early July 2021, it was reported that the Federal Office of Energy had engaged in talks with the operators of the remaining four reactors about a potential lifetime extension to 60 years. However, in Switzerland, there is no specific time limit on operational licenses. Nuclear reactors can operate as long as they are deemed safe by the safety authorities and two units have already passed 50 years in operation. The Swiss Energy Foundation has called lifetime extensions "an unnecessary and dangerous game to gain time".[2253]

On 21 May 2017, 58 percent of Swiss voters agreed to the "Energy Strategy 2050" plan that provides a long-term policy framework based on the dynamic development of energy efficiency and renewable energies. The strategy does not fix any closure dates for the nuclear power plants and aims to keep the existing reactors operating "as long as they are safe". However, it prohibits the construction of new nuclear power plants, "fundamental changes" to operating reactors, and the reprocessing of spent fuel. The "totally revised energy legislation" entered into force on 1 January 2018.[2254]

2252 - Manfred Mertins, "Studie zu den Sicherheitsdefiziten des Schweizer AKW Leibstadt (Defizit-Studie KKL)", TH Brandenburg, commissioned by Schweizerische Energiestifung/Swiss Energy Foundation (in German) August 2021, see https://energiestiftung.ch/files/energiestiftung/publikationen/pdf/20210829_Studie%20zu%20den%20Sicherheitsdefiziten%20des%20Schweizer%20AKW%20Leibstadt_final.pdf, accessed 10 September 2023.

2253 - Michel Sutter, "Laufzeitverlängerung der Kernkraftwerke sorgt für Diskussionen", *energate messenger*, 7 May 2021 (in German), see https://www.energate-messenger.ch/news/213514/laufzeitverlaengerung-der-kernkraftwerke-sorgt-fuer-diskussionen, accessed 5 July 2021.

2254 - UVEK and BFE, "Wichtigste Neuerungen im Energierecht ab 2018", Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation/Federal Department of the Environment, Transport, Energy and Communications, and Bundesamt für Energie/Swiss Federal Office of Energy, 2 November 2017 (in German), see https://www.newsd.admin.ch/newsd/message/attachments/50166.pdf, accessed 13 July 2018.

The legislation is comprehensive, providing a framework for the development of grid regulation, renewable energy incentives, auto-consumption, energy efficiency and the "organic phaseout" of nuclear power. The efficiency targets are ambitious, with reduction of per-capita energy consumption levels—compared to the 2000 baseline—by 16 percent by 2020 and 43 percent by 2035, while per-capita electricity consumption was to decrease by 3 percent by the end of 2020 and 13 percent by 2035.[2255] The 2020 target was superseded by 4.8 percent, resulting in a reduction of per-capita end-energy consumption by 20.8 percent compared to 2000. While the COVID-19 pandemic played a major role in the decline that year, the Swiss Federal Office of Energy notes that the target had already been "undercut in the last three years prior to the COVID-19 pandemic", concluding that it was "highly likely that the applicable target in the Energy Act for 2020 would also have been achieved without the influence of the pandemic."[2256]

Since then, legislation has further solidified Swiss commitment to climate neutrality by 2050. The Swiss nationally determined contribution, submitted in 2022 under the Paris Agreement, now envisions a reduction of greenhouse gas emissions by "at least 50 percent" by 2030, compared to 1990 levels, while this target had previously been set as an upper limit.[2257] In 2023, the new "Climate and Innovation Act" was accepted in a referendum with a 59.1 percent majority. The act aims at reducing the consumption of oil and gas solely by implementing incentives and avoids banning technologies. Rather, funding is provided for "climate friendly heating" and "innovative technologies and processes" are to be supported. Further, government assets, in their function as role models, shall reduce their emissions to zero by 2040, while industrial actors shall do so by 2050.[2258]

Domestic production of non-hydro renewable-energy based electricity increased by 20 percent in 2022 to reach a modest 6 TWh, representing only 9 percent of the power generated in the country, while hydro generation dropped to 52.8 percent of the country's electricity (against 61.5 percent in 2021).[2259]

Switzerland is strongly reliant on Russia's Rosatom for its enriched uranium. Half of the fuel material for Leibstadt and all of it for Beznau is of Russian origin. Since Russia's attack on Ukraine, Axpo, the operator at both plants, has been facing criticism regarding its continued cooperation with Rosatom.[2260] Axpo said that it would honor the contracts for Beznau (until

2255 - SFOE, "Energy Strategy 2050 Once the New Energy Act is in Force", Swiss Federal Office of Energy, 18 January 2018, see https://www.bfe.admin.ch/bfe/en/home/politik/energiestrategie-2050/dokumentation.exturl.html, accessed 10 September 2023.

2256 - SFOE, "Energy Strategy 2050 - Monitoring Report 2021", Swiss Federal Office of Energy, December 2021, see https://www.bfe.admin.ch/bfe/en/home/versorgung/statistik-und-geodaten/monitoring-energiestrategie-2050.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZW4vcHVibGljYX/Rpb24vZG93bmxvYWQvMTA3NzM=.html, accessed 14 September 2023.

2257 - FOEN, "Switzerland's submissions within the framework of international climate negotiations (UNFCCC): 2022", Federal Office for the Environment, Updated 8 May 2023, see https://www.bafu.admin.ch/bafu/en/home/themen/thema-klima/klimawandel-stoppen-und-folgen-meistern/klima--internationales/eingaben-der-schweiz-im-rahmen-der-internationalen-klimaverhandl/eingaben-der-schweiz-im-rahmen-der-internationalen-klimaverhandlungen-unfccc-2021.html, accessed 10 September 2023.

2258 - UVEK/DETEC, "Klima- und Innovationsgesetz", Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikatoin/Federal Department of the Environment, Transport and Communications, 18 June 2023 (in German), see https://www.uvek.admin.ch/uvek/de/home/uvek/abstimmungen/klima-und-innovationsgesetz.html, accessed 14 September 2023.

2259 - BFE/OFEN, "Schweizerische Elektrizitätsstatistik 2022 / Statistique suisse de l'électricité 2022", June 2023, op. cit.

2260 - Res Gehringer and Sascha Buchbinder, "Russische Brennstäbe für Schweizer AKW", *SRF Rundschau*, 31 March 2022 (in German), see https://www.srf.ch/news/international/axpo-in-der-kritik-russische-brennstaebe-fuer-schweizer-akw, accessed 10 September 2023.

2030) and Leibstadt (until 2025), but will not extend cooperation.[2261] Apparently, the utility could face fees up to CHF 200 million (US$ $_{2023}$224 million) if it were to walk away from the contracts. Nonetheless, in August 2022, the utility claimed that there would be no Russian uranium coming to Europe due to blocked trade routes.[2262] However, reports suggest that in November 2022, Russian ship "Mihkail Dudin" set sail to transport uranium to Rotterdam, that would be transported to the fuel plant in Lingen, Germany, from where 44 fuel assemblies were to be transported to Beznau and 80 fuel assemblies to Leibstadt. Reportedly, this is confirmed by German export documents. Axpo neither confirmed or denied these reports.[2263] At Lingen, French company Framatome and Rosatom are planning to cooperate via a French joint venture company after withdrawing—a few days prior to the invasion of Ukraine—a previous application filed with the German authorities (see Other Nuclear Developments in Germany in Germany Focus).[2264] Axpo itself says that it has enough fuel reserves to operate its plants for several years.[2265]

On 10 September 2022, Switzerland concluded a major step in developing a final nuclear waste depository when the National Cooperative for the Disposal of Radioactive Waste (Nagra) announced the proposed location for the site, at Northern Lägern, close to the German border. The application for the construction of the repository is to be submitted by the end of 2024, while the final governmental decision is not expected before 2029 (and will probably have to be validated through public consensus, anticipated for 2031). Current plans envision initial construction work for underground geological investigation in 2034, construction begin in 2045 and the first deposition of waste around 2050–2060.[2266]

United Kingdom

See Focus Countries – United Kingdom Focus.

2261 - Fabian Hägler, "Russisches Atomschiff unterwegs – mit Uran für Aargauer Kernkraftwerke?" *Aargauer Zeitung*, 11 November 2022 (in German), see https://www.aargauerzeitung.ch/aargau/kanton-aargau/uran-doch-wieder-russisches-uran-fuer-aargauer-atomkraftwerke-axpo-kann-umstrittene-lieferung-nicht-ausschliessen-ld.2371501?, accessed 10 September 2023.

2262 - Stefan Häne, "Axpo will neue Partner, ohne Russland zu vergraulen", *Tages-Anzeiger*, 11 August 2022 (in German), see https://www.tagesanzeiger.ch/axpo-will-neue-partner-ohne-russland-zu-vergraulen-669252921640, accessed 10 September 2023.

2263 - Stefan Häne, "Importiert die Axpo doch wieder russisches Uran?", *Tages-Anzeiger*, 11 November 2022 (in German), see https://www.tagesanzeiger.ch/importiert-axpo-doch-wieder-russisches-uran-724530496073, accessed 10 September 2023.

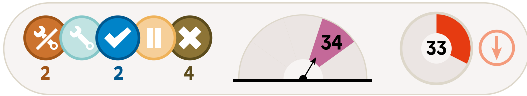
2264 - *dpa*, "Joint Venture stellt Brennelemente her", *Deutsche Presse-Agentur*, as published in *Süddeutsche Zeitung* (in German), 30 March 2023, see https://www.sueddeutsche.de/wissen/atom-lingen-ems-joint-venture-stellt-brennelemente-her-dpa.urn-newsml-dpa-com-20090101-230330-99-142358, accessed 10 September 2023.

2265 - Fabian Hägler, "Russisches Atomschiff unterwegs – mit Uran für Aargauer Kernkraftwerke?", *Aargauer Zeitung*, November 2022, op. cit.; and Stefan Häne, "Schweizer Kernkraftwerke beziehen Uran aus Russland", *Der Bund*, 1 March 2022 (in German), see https://www.derbund.ch/schweizer-kernkraftwerke-beziehen-uran-aus-russland-917246134946, accessed 10 September 2023.

2266 - Nagra, "The Site for the Deep Geological Repository—Nagra's Proposal", Nationale Genossenschaft für die Lagerung radioaktiver Abfälle/National Cooperative for the Disposal of Radioactive Waste, September 2022, see https://nagra.ch/wp-content/uploads/2022/09/Report-the-site-for-the-deep-geological-repository-Nagras-proposal.pdf; and *SWI swissinfo.ch*, "Site in northern Switzerland chosen for nuclear waste storage", 10 September 2022, see https://www.swissinfo.ch/eng/sci-tech/site-in-northern-switzerland-chosen-for-nuclear-waste-storage-/47890816; both accessed 10 September 2023.

CENTRAL AND EASTERN EUROPE

Bulgaria



In Bulgaria, nuclear power provided a stable 15.8 TWh while the nuclear share dropped from 34.6 percent to 32.6 percent of the country's electricity in 2022, down from a maximum of 47.3 percent in 2002. This is produced by two VVER-1000 reactors at Kozloduy.

Originally, there were six reactors at the Kozloduy site, but the oldest four (VVER-440 v230) were closed as part of an agreement by the G7 in Munich in 1992—as they were considered impossible to be "economically upgraded to a required level of safety"—and implemented through the agreement for Bulgaria to join the European Union in 2007.[2267] Both operational VVER-1000 (V-320) reactors (Units 5 and 6), that started up in 1987 and 1991, respectively, are undergoing a relicensing program intended to extend their operating lifetimes up to 60 years, compared to their original 30-year license. In 2017, Unit 5 was awarded an additional 10-year operating license to enable it to continue operating until 2027, and in October 2019, Unit 6 was granted a license to operate until 2029. Reportedly, the total cost of the two-unit extension program was just BGN292 million (US$\$_{2019}$163 million),[2268] which seems extraordinarily cheap compared to lifetime extension program costs in other countries. An IAEA review conducted in June 2023 concluded that the plant's operator had "completed all major actions to safely operate the reactors in the LTO [long-term operation] period". Further work however was necessary concerning the proper implementation of new ageing management programs for mechanical components and cables.[2269]

Bulgaria is heavily dependent on Russia for its energy supplies, including, until the Russian attack on Ukraine in February 2022, for 70 percent of its natural gas. As of mid-2023, Bulgarian gas supply was entirely cut off by Russia. The acting government had secured supply for 2023 from Greek and Turkish LNG terminals while tenders for LNG supply for 2024 to 2034 were still ongoing.[2270] The country's only oil refinery is owned by Russian company Lukoil and as of May 2022, about 50 percent of the processed crude oil was of Russian origin.[2271] Although the E.U. banned oil imports from Russia, in June 2022 Bulgaria received a temporary exemption

2267 - European Commission, "Proposal for a Council Regulation on Community Financial Assistance with Respect to the Decommissioning of Units 1 to 4 of the Kozloduy Nuclear Power Plant in Bulgaria", Commission Staff Working Document COM(2009) 581 final, 27 October 2009, see https://data.consilium.europa.eu/doc/document/ST-15112-2009-ADD-1/en/pdf; and Michael Winfrey, "Bulgaria fumes as EU demands nuke reactor shutdowns", *Reuters*, 21 January 2007, see https://www.reuters.com/article/uk-eu-candidates-nuclear-idUSL0585015220061227; both accessed 26 July 2023.

2268 - *WNN*, "Kozloduy unit 6 clear to operate for another 10 years", *World Nuclear News*, 2 October 2019, see https://www.world-nuclear-news.org/Articles/Kozloduy-unit-6-clear-to-operate-for-another-10-ye, accessed 4 April 2021.

2269 - IAEA, "IAEA Concludes Long Term Operation Safety Review at Bulgaria's Kozloduy Nuclear Power Plant", Press Release 57/2023, International Atomic Energy Agency, 16 June 2023, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operation-safety-review-at-bulgarias-kozloduy-nuclear-power-plant, accessed 23 June 2023.

2270 - Luka Dimitrov, "Cheniere, TotalEnergies LNG cargoes to boost Bulgaria's April gas supply", Independent Commodity Intelligence Services, 30 March 2023, see https://www.icis.com/explore/resources/news/2023/03/30/10871148/cheniere-total-lng-cargoes-to-boost-bulgaria-s-april-gas-supply/, accessed 26 July 2023.

2271 - Tsvetelia Tsolova, "Bulgaria to seek exemption from EU oil embargo on Russia if possible, deputy PM says", *Reuters*, 4 May 2022, see https://www.reuters.com/business/energy/bulgaria-seek-exemption-any-eu-embargo-russian-oil-deputy-pm-says-2022-05-04/, accessed 4 August 2023.

valid until December 2024[2272], and proceeded to process only Russian crude. Legislation enabling to take control of the refinery (for a limited period) if necessary was approved in January 2023.[2273] Between January and September 2023, 92 percent of Bulgaria's oil was imported from Russia.[2274]

Bulgaria is also dependent on Russian deliveries of equipment and fuel for Kozloduy. At the start of the war, Prime Minister Petkov stressed that Bulgaria had nuclear fuel for two years and there was no immediate threat to Bulgaria's nuclear energy production,[2275] but Bulgaria is regardless seeking to diversify its nuclear fuel supply-sources. In November 2022, the Bulgarian parliament voted with a three-quarter majority to shift nuclear fuel supply away from Russian sources[2276], although a delivery contract had been signed in December 2019 with Russian fuel company TVEL for both units at Kozloduy until 2025[2277]. In 2021, in a step to implement the E.U.'s Energy Security Strategy that demands the diversification of nuclear supplies and services, Westinghouse and Kozloduy's operator had already signed a licensing contract for fuel to be used at Unit 5[2278], and following the above-mentioned vote in Bulgarian parliament, a ten-year contract with Westinghouse was signed in December 2022 to begin supplying fuel to Unit 5 by 2024.[2279] The approval process for fuel delivery began in July 2023.[2280] Further it was announced end-2022 that Unit 6 was to be supplied with fuel from Framatome from 2025 to 2034. The agreement reportedly "sets the out the schedule for future negotiations and the conclusion of a contract."[2281] Further details were not disclosed, and as Framatome currently lacks production capacities for VVER fuel, it remains unclear how it would be provided[2282] (see Germany Focus). In March 2023, Bulgaria was granted an exemption by the E.U. from import

2272 - European Commission, "Russia's war on Ukraine: EU adopts sixth package of sanctions against Russia", Press Release, 3 June 2022, see https://ec.europa.eu/commission/presscorner/detail/en/IP_22_2802, accessed 4 November 2023.

2273 - Tsvetelia Tsolova, "Bulgaria clears way to take control of Lukoil oil refinery if needed", *Reuters*, 13 January 2023, see https://www.reuters.com/business/energy/bulgaria-clears-way-take-control-lukoil-oil-refinery-if-needed-2023-01-13/, accessed 4 August 2023.

2274 - *Reuters*, "Bulgaria steps up non-Russian oil imports in October -LSEG data", 16 October 2023, see https://www.reuters.com/markets/commodities/bulgaria-steps-up-non-russian-oil-imports-october-lseg-data-2023-10-16/, accessed 4 November 2023.

2275 - Emiliya Milcheva and Krasen Nikolov, "Nuclear project with Russian reactors shakes Bulgarian politics", *Euractiv*, 21 February 2022, see https://www.euractiv.com/section/politics/short_news/nuclear-project-with-russian-reactors-shakes-bulgarian-politics/, accessed 8 July 2022.

2276 - *WNN*, "Bulgarian parliament votes to switch from Russian nuclear fuel", *World Nuclear News*, 10 November 2022, see https://www.world-nuclear-news.org/Articles/Bulgarian-parliament-votes-to-switch-from-Russian, accessed 26 July 2023.

2277 - TVEL, "TVEL and Kozloduy NPP have contracted supplies of Russian nuclear fuel to Bulgaria through 2025", 19 December 2019, see https://www.tvel.ru/en/press-center/news/?ELEMENT_ID=8140, accessed 19 July 2023.

2278 - *NEI Magazine*, "Kozloduy NPP signs licensing contract for Westinghouse fuel", *Nuclear Engineering International*, 8 February 2021, see https://www.neimagazine.com/news/newskozloduy-npp-signs-licensing-contract-for-westinghouse-fuel-8502347, accessed 3 August 2023.

2279 - Westinghouse, "Westinghouse's VVER-1000 Nuclear Fuel Fabrication Agreement Helps Cement Bulgaria's Energy Security", Press Release, 22 December 2022, see https://info.westinghousenuclear.com/uk/news-insights/westinghouse-vver-1000-nuclear-fuel-fabrication-agreement-helps-cement-bulgarias-energy, accessed 4 November 2023.

2280 - BNRA, "Стартира лицензионният процес на новото ядрено гориво за блок 5 на АЕЦ „Козлодуй"" ["The licensing process of the new nuclear fuel for Kozloduy NPP Unit 5 has started"]", Press Release, Nuclear Regulatory Agency of Bulgaria, 20 July 2023, see https://bnra.bg/bg/novini-bnra/startira-litsenzionniyat-protses-na-novoto-yadreno-gorivo-za-blok-5-na-aets-kozloduy/, *accessed 4 November 2023;*

2281 - *WNN*, "Kozloduy and Framatome sign nuclear fuel agreement", *World Nuclear News*, 4 January 2023, see https://world-nuclear-news.org/Articles/Kozloduy-and-Framatome-sign-nuclear-fuel-agreement, accessed 15 November 2023.

2282 - *The Sofia Globe*, "Bulgaria's Kozloduy nuclear power station signs fuel agreement with Framatome", 30 December 2022, see https://sofiaglobe.com/2022/12/30/bulgarias-kozloduy-nuclear-power-station-signs-fuel-agreement-with-framatome/, accessed 5 August 2023.

restrictions to allow for Russian parts and materials to be brought into the country for the annual maintenance of Kozloduy.[2283]

There have been ongoing attempts to build another nuclear power plant at Belene in Northern Bulgaria. Construction started in 1987 but was halted in 1990 and suspended indefinitely in 1991. Work officially resumed in 2008 but was abandoned again in 2012.[2284] In 2018, the Government once again revived the project and began searching for new investors,[2285] and then in March 2019, the Government announced that it was preparing to select a single strategic investor and started a tender procedure, which officially started after publication in the *EU Official Journal* in May of the same year. Initial interest was expressed by Framatome, General Electric, China National Nuclear Corporation (CNNC) and Rosatom.[2286]

In December 2019, during a visit from then Prime Minister Boyko Borisov to the U.S., conversations were held with President Trump about the construction of Belene, including the supply of turbines by American firms. Only a few weeks later, the Bulgarian Government announced that five companies had been shortlisted for negotiations, namely CNNC, Korea Hydro & Nuclear Power (KHNP), Framatome, General Electric (GE) and Rosatom's subsidiary Atomenergoprom,[2287] although Russia very much saw the project as its own as Russian reactor manufacturer Atomstroyexport, subsidiary of Rosatom, had been involved in prior development efforts at Belene.[2288] Framatome and GE were shortlisted to supply either the project turbine island (GE) or I&C—Instrumentation and Control systems—(Framatome) rather than the whole reactor. The finalists were expected to submit binding bids by the end of January 2020. The Government announced that investors would be able to negotiate electricity purchases with companies seeking to acquire minority stakes in Belene.[2289] In February 2022, French state-owned utility EDF and GE signed an exclusive agreement for EDF to acquire GE's Steam Power division, including the nuclear island engineering section and the Arabelle turbine licenses.[2290] If the Belene project advances, it might thus well become a mostly French project.

However, despite some developments, procedures were halted due to the coronavirus pandemic, and in January 2021, the Government appeared to have abandoned once again the plans for construction of a reactor at Belene. This was reported by *Euractiv* as "this third suspension is

2283 - *NEI Magazine*, "Bulgaria to continue imports from Russia for Kozloduy NPP", *Nuclear Engineering International*, 24 March 2023, see https://www.neimagazine.com/news/newsbulgaria-to-continue-imports-from-russia-for-kozloduy-npp-10701347, accessed 26 July 2023.

2284 - *WNN*, "Bulgarian government drops Belene", *World Nuclear News*, 29 March 2012, see https://www.world-nuclear-news.org/Articles/Bulgarian-government-drops-Belene, accessed 26 July 2023.

2285 - *WNN*, "Bulgarian parliament approves restart of Belene investor talks", *World Nuclear News*, 8 June 2018, see https://www.world-nuclear-news.org/Articles/Bulgarian-parliament-approves-restart-of-Belene-in, accessed 26 July 2023.

2286 - *NEI Magazine*, "Bulgaria launches call for strategic investor for Belene NPP", 24 May 2019, see https://www.neimagazine.com/news/newsbulgaria-launches-call-for-strategic-investor-for-belene-npp-7224432, accessed 26 July 2023.

2287 - Kamen Kraev, "Bulgaria To Invite Five Companies To Participate In New Build Project", *NucNet*, 20 December 2019, see https://www.nucnet.org/news/belene-bulgaria-to-invite-five-companies-to-participate-in-new-build-project-12-5-2019, accessed 26 July 2023.

2288 - *NEI Magazine*, "Belene moves forward", 25 June 2009, see https://www.neimagazine.com/features/featurebelene-moves-forward/, accessed 3 August 2023.

2289 - Kamen Kraev, "Bulgaria To Invite Five Companies To Participate In New Build Project", *NucNet*, 20 December 2019, see https://www.nucnet.org/news/belene-bulgaria-to-invite-five-companies-to-participate-in-new-build-project-12-5-2019, accessed 26 July 2023.

2290 - EDF and GE, "EDF signe un accord d'exclusivité pour l'acquisition d'une partie de l'activité nucléaire de GE Steam Power", Press Release (in French), 10 February 2022, see https://www.edf.fr/sites/groupe/files/2022-02/b5689a51907536d4776fe6bb1f31d4b4.pdf, accessed 4 August 2023.

likely to end the Belene nuclear project forever".[2291] Nevertheless, this was not officially the end of nuclear new-build, with suggestions that attention should once again be focused on building a seventh reactor at Kozloduy, which would include the transfer of equipment from Belene.[2292] This was confirmed in February 2022 by Prime Minister Kiril Petkov, who suggested that two new units could be built at Kozloduy.[2293]

In January 2023, despite ongoing coalition talks that hindered the implementation of a functioning government,[2294] acting Energy Minister Rossen Hristov announced Bulgaria's energy strategy for 2023 to 2053 with plans to eliminate coal by 2038, albeit beginning to reduce coal usage only in 2030, while emphasizing Bulgaria's role as electricity exporter in the region.[2295] The plan includes the installation of 7 GW of solar and 2 GW of wind power by 2030, to be increased by 12GW and 4 GW by 2050, respectively. Battery storage, electric vehicle charging stations and additional hydropower are also envisioned. Most notably however are the plans to increase nuclear power capacities. At the Belene site, the strategy reportedly sees 2 GW of nuclear capacity by 2035–2040. 2 GW of nuclear capacity are to be constructed at Kozloduy by 2045 as a replacement for the currently operating Units 5 and 6.[2296]

In the meantime, the Bulgarian parliament passed a motion in January 2023 to force the acting government to speed up the license approval and construction process of the planned 7th reactor at Kozloduy. The vote also motioned the government to begin licensing and environmental impact assessment procedures for an 8th reactor. Most parties believe that nuclear power capacities should be increased, but opinions differ in terms of prioritizing the Kozloduy or Belene sites.[2297] In March 2023, state-owned company Kozloduy NPP-Newbuild signed an MoU with U.S. manufacturer Westinghouse to begin the planning of one or two AP-1000 PWRs at the Kozloduy site.[2298] Vague plans to build NuScale SMRs at the location[2299] seem to have been scrapped.

In parallel to signing agreements with Westinghouse, the Bulgarian energy ministry has agreed upon conducting a pre-project engineering study with EDF for the Belene site. Equipment at Belene that had been bought from Rosatom for €620 million (US$$_{2023}$678 million) was originally

2291 - Krassen Nikolov, "Bulgaria puts end to Belene nuclear project", *Euractiv.bg*, 21 January 2021, see https://www.euractiv.com/section/politics/short_news/bulgaria-puts-end-to-belene-nuclear-project/, accessed 4 April 2021.

2292 - *NEI Magazine*, "Bulgaria considers using Belene reactors to expand Kozloduy plant", 25 January 2021, see https://www.neimagazine.com/news/newsbulgaria-considers-using-belene-reactors-to-expand-kozloduy-plant-8472288/, accessed 4 April 2021.

2293 - Mihajlo Vujasin, "Bulgaria abandons Belene, announces new reactors at Kozloduy", *Balkan Green Energy News*, 16 February 2022, see https://balkangreenenergynews.com/bulgaria-abandons-belene-announces-new-reactors-at-kozloduy/, accessed 13 July 2022.

2294 - Bulgaria has seen five parliamentary elections in the last two years; see Roumen Radev, "We Continue the Change-Democratic Bulgaria coalitions accepts mandate to seek to form a government", *The Sofia Globe*, 29 May 2023, see https://sofiaglobe.com/2023/05/29/we-continue-the-change-democratic-bulgaria-coalition-accepts-mandate-to-seek-to-form-a-government/, accessed 30 May 2023.

2295 - *WNN*, "Bulgaria energy strategy includes four new nuclear reactors", *World Nuclear News*, 19 January 2023, see https://www.world-nuclear-news.org/Articles/Bulgaria-sets-out-plans-for-four-new-nuclear-react, accessed 22 January 2023.

2296 - *Balkan Green Energy News*, "Bulgaria's 2053 energy strategy: coal until 2030, new nuclear capacities", 18 January 2023, see https://balkangreenenergynews.com/bulgarias-2053-energy-strategy-coal-until-2030-new-nuclear-capacities/, accessed 30 May 2023.

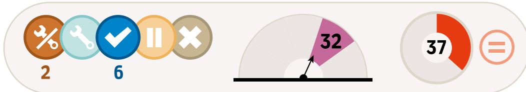
2297 - *WNN*, "Bulgarian parliament backs new AP1000 reactor at Kozloduy", *World Nuclear News*, 16 January 2023, see https://www.world-nuclear-news.org/Articles/Bulgarian-parliament-backs-new-AP1000-reactor-at-K, accessed 16 January 2023.

2298 - Kamen Kraev, "Westinghouse Signs Agreement To Begin Planning For New Nuclear At Kozloduy", *NucNet*, 3 March 2023, see https://www.nucnet.org/news/westinghouse-signs-deal-to-begin-planning-for-new-nuclear-at-kozloduy-3-5-2023, accessed 30 May 2023.

2299 - *Balkan Green Energy News*, "Romania, Bulgaria to build small nuclear power plants", 1 November 2021, see https://balkangreenenergynews.com/romania-bulgaria-intend-to-build-small-nuclear-power-plants/, accessed 30 May 2023.

planned to be reused. But given the shift from Russian design to American or French nuclear reactors, it remains uncertain whether this is possible.[2300] Earlier discussions on the project had in 2021 sought to use "a Russian reactor, but American technology" – an approach that would have required the participation of Rosatom. By early 2022, a cooperation of U.S. and Russian nuclear manufacturers seemed impossible.[2301]

Czech Republic



The Czech Republic has six Russian-designed reactors in operation at two sites, Dukovany and Temelín. The former houses four VVER-440 v213 reactors, the latter two VVER-1000 v320 units. In 2022, nuclear plants production remained stable with 29.3 TWh, representing a 36.7 percent share in electricity production.

In May 2022, ČEZ, the 70-percent-state-owned utility[2302], announced that it had received an indefinite operating license for Temelín-2, on the grid since 2002, with a caveat that it meets the continual conditions for safe operation from the regulator, the State Office for Nuclear Safety (SÚJB).[2303]

Temelín-1, commissioned in 2000, had received a ten-year license renewal in September 2020.[2304] ČEZ is planning to extend operating cycles at both units from 12 to 18 months and is investing this year CZK3.6 billion (US$$_{2023}$166 million) for the modernization of the reactors in view of extended lifetime operations to at least 60 years of operation. Since startup, reportedly a total of over CZK28 billion (US$$_{2023}$1.29 billion) have been invested for upgrading the plant.[2305]

The Dukovany units were started up between 1985 and 1987 and have already undergone a lifetime-extension upgrading-program under the expectation they would operate until 2025. In March 2016, SÚJB extended the operating license of Dukovany-1 indefinitely,[2306] which was soon followed by indefinite extensions for the other three units.[2307] The operator expects that the plant will operate until 2037[2308] with the possibility of extension of the reactor in

2300 - Stoyan Nenov and Alan Charlish, "Westinghouse and EDF to conduct pre-project nuclear power studies in Bulgaria", *Reuters*, 28 March 2023, see https://www.reuters.com/business/energy/westinghouse-edf-conduct-pre-project-nuclear-power-studies-bulgaria-2023-03-28/, accessed 26 July 2023.

2301 - Emiliya Milcheva and Krasen Nikolov, "Nuclear project with Russian reactors shakes Bulgarian politics", *Euractiv*, 21 February 2022, see https://www.euractiv.com/section/politics/short_news/nuclear-project-with-russian-reactors-shakes-bulgarian-politics/, accessed 8 July 2022.

2302 - CEZ Group, "About us— ČEZ, a. s—Shareholders", 2023, see https://www.cez.cz/en/cez-group/cez/structure-of-shareholders, accessed 26 July 2023.

2303 - *NEI Magazine*, "Temelin 2 receives permit for extended operation", *Nuclear Engineering International*, 1 June 2022, see https://www.neimagazine.com/news/newstemelin-2-receives-permit-for-extended-operation-9737994, accessed 26 July 2023.

2304 - David Dalton, "Regulator Gives 10-Year Licence Renewal For Temelín-1", *NucNet*, 25 September 2020, see https://www.nucnet.org/news/regulator-gives-10-year-licence-renewal-for-temelin-1-9-5-2020, accessed 2 August 2023.

2305 - *WNN*, "Modernisation projects under way at Czech plants", *World Nuclear News*, 15 February 2023, see https://world-nuclear-news.org/Articles/Modernisation-projects-under-way-at-Czech-plants, accessed 2 August 2023.

2306 - David Dalton, "Dukovany-2 And -3 To Undergo Extended Checks On Pipe Welds", *NucNet*, 13 May 2016, see https://www.nucnet.org/all-the-news/2016/05/13/dukovany-2-and-3-to-undergo-extended-checks-on-pipe-welds, accessed 9 April 2021.

2307 - *NEI Magazine*, "A view over Europe", *Nuclear Engineering International*, 28 March 2018, see https://www.neimagazine.com/features/featurea-view-over-europe-6098537/, accessed 2 August 2023.

2308 - ČEZ, "NPP Dukovany", CEZ GROUP, Undated, see http://www.cez.cz/en/energy-generation/nuclear-power-plants/dukovany, accessed 26 July 2023.

alignment with the others on-site until 2047.[2309] To allow for the operation of the plant "for at least 60 years", in early 2023, ČEZ announced it would be spending around CZK2.3 billion (US$$_{2023}$106 million) during the year—28 percent more than in the previous year—mainly for extending refueling cycles for all four reactors from 12 to 16 months and begin the construction of a new administrative building on-site to house more than 100 additional workers.[2310] No estimate of total refurbishment and upgrading costs has been published.

This refueling-cycle extension goes hand in hand with Czech efforts to switch fuel supply away from Russian sources. Starting in 2024, all four VVER-440 reactors at Dukovany are to be supplied with fuel manufactured by Westinghouse.[2311] Russian fuel is also to be replaced at Temelín by a consortium of Framatome and Westinghouse for at least ten years from 2024 onwards.[2312] The latter had already supplied fuel to Temelín in the first decade of operations[2313], but the operators had switched to Russian supplier TVEL, supposedly for economic reasons in 2010.[2314] However, there had also been technical difficulties with Westinghouse's VVER-1000 fuel that might have led to the decision to switch suppliers.[2315] In 2019, six test assemblies manufactured by Westinghouse were loaded into Temelín-1,[2316] likely easing the return to Western suppliers. This development is part of ongoing Czech efforts to shift energy reliance away from Russia. Before Russia's invasion of Ukraine, about 50 percent of oil supply and most natural gas came from Russian sources. These are now being diversified via other pipelines and LNG import capacities via Dutch terminals.[2317]

Over the past two decades the Government and industry have announced new initiatives to build additional reactors. In May 2018, it was reported that the government had postponed a decision on nuclear newbuild saying it needed more time to evaluate the impact on its

2309 - European Commission, "Progress of implementation of Council Directive 2011/70/EURATOM Accompanying the document Report from the Commission to the Council the European Parliamenton progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects", December 2019, see https://www.parlament.gv.at/dokument/XXVII/EU/7208/imfname_10949006.pdf, accessed 26 July 2023.

2310 - *WNN*, "ČEZ increases investment in Dukovany, 16-month fuel cycles", *World Nuclear News*, 2 February 2023, see https://www.world-nuclear-news.org/Articles/CEZ-increases-investment-in-Dukovany,-16-month-fue, accessed 4 February 2023.

2311 - Westinghouse, "Westinghouse Reinforces its Commitment to Energy Security in Czech Republic", Press Release, 29 March 2023, see https://info.westinghousenuclear.com/news/westinghouse-reinforces-its-commitment-to-energy-security-in-czech-republic; and *WNN*, "Westinghouse to supply fuel to Czech Republic's Dukovany", *World Nuclear News*, 30 March 2023, see https://www.world-nuclear-news.org/Articles/Westinghouse-to-supply-fuel-to-Czech-Republic-s-Du; both accessed 6 November 2023.

2312 - ČEZ, "We are strengthening the energy security of the Czech Republic: we have signed contracts for the supply of fuel assemblies with Westinghouse and Framatome", Press Release, 28 June 2023, see https://www.cez.cz/en/media/press-releases/we-are-strengthening-the-energy-security-of-the-czech-republic-we-have-signed-contracts-for-the-supply-of-fuel-assemblies-with-westinghouse-and-framatome-160156; and ČEZ, "Americans and French will supply nuclear fuel to Temelín", Press Release, 14 April 2022, see https://www.cez.cz/en/media/press-releases/americans-and-french-will-supply-nuclear-fuel-to-temelin-157447; both accessed 26 July 2023

2313 - Jan Höglund and Ulf Benjaminsson, "New fuel for Temelín 1", Technical Lead for Fuel Engineering, and Fuel Marketing Manager, Westinghouse, as published in *NEI Magazine*, 3 October 2019, *Nuclear Engineering International*, see https://www.neimagazine.com/features/featurenew-fuel-temelin-1-7436970/, accessed 2 August 2023.

2314 - *NEI Magazine*, "TVEL to supply fuel for Temelin", *Nuclear Engineering International*, 22 July 2010, see https://www.neimagazine.com/news/newstvel-to-supply-fuel-for-temelin, accessed 2 August 2023.

2315 - Daniel Ernst and Lukáš Milisdörfer, "10 years of experience with Westinghouse fuel at NPP Temelín", ČEZ, as presented at the VVER 2010 Conference, 1–3 November 2010, see https://inis.iaea.org/collection/NCLCollectionStore/_Public/42/016/42016135.pdf, accessed 2 August 2023.

2316 - Jan Höglund and Ulf Benjaminsson, "New fuel for Temelín 1", Westinghouse, *NEI Magazine*, 3 October 2019, op. cit.; and *WNN*, "ČEZ set to test Westinghouse fuel at Temelín", *World Nuclear News*, 5 April 2019, see https://world-nuclear-news.org/Articles/CEZ-set-to-test-Westinghouse-fuel-at-Temelin, accessed 2 August 2023.

2317 - Krzysztof Dębiec, "The TAL is expanding: the Czech Republic is gaining independence from Russian oil supplies", Ośrodek Studiów Wschodnich/Centre for Eastern Studies, 7 December 2022, see https://www.osw.waw.pl/en/publikacje/analyses/2022-12-07/tal-expanding-czech-republic-gaining-independence-russian-oil, accessed 26 July 2023.

budget and find out the E.U. views on state aid for such a project.[2318] On 13 November 2019, the Czech parliamentary committee for the construction of new nuclear resources approved the construction of the Dukovany II nuclear plant.[2319] Subsequently, then-Prime Minister Andrej Babis said that they would start construction in 2029 with first power production in 2036. This would require holding a tender in 2021 and select a vendor by the end of 2022, two years ahead of the previous tentative schedule.[2320]

Then-Minister of Industry Karel Havlícek told reporters in February 2020 that by the end of 2022 the supplier would have been selected.[2321] In March 2020, ČEZ applied to SÚJB for the construction license of two 1,200-MW units at the Dukovany site. In June 2020, the government announced that it had agreed on a financing model whereby the government would provide a loan covering 70 percent of the project's approximate US$6 billion price tag, while ČEZ will have to front the remaining 30 percent on its balance sheet. The plan was to launch a tender in late 2020.[2322]

The government was expected to prepare—by the end of June 2020—draft contracts with ČEZ and its project company subsidiary that would establish a long-term (30-40 years) offtake agreement from the prospective newbuild, to give the project greater financial security. It was also suggested that the government was prepared to insulate the project from legislative and regulatory risks, so that if a subsequent government were to phase out nuclear power, it would be committed to buy the project and reimburse the investors.[2323] It is not clear how the contracts between the state and ČEZ will be drawn up to provide such guarantees to ČEZ and minority shareholders. Current plans might lead to ČEZ restructuration, leading to full state responsibility of nuclear projects. [2324]

By 2021, the government's intention was to conduct safety assessments of potential applicants over the course of 2021 to launch a tender in December 2021 that would conclude in 2023. ČEZ hoped to finalize a supply contract by 2024 and start building in 2029.[2325]

The choice of vendor for the project is controversial and could even threaten the whole project. Initially five designs were said to be in the running, including Korea Electric Power Co's (KEPCO) "APR1000+", a revised, downsized EPR from EDF ("EPR1200", a design that has not been completed on paper and is not certified anywhere), both of which are yet to be built anywhere, an AP-1000 from Westinghouse, and reactors from China General Nuclear Power Corporation (CGN) and Rosatom of Russia. However, in early 2021, CGN was ejected from the process—officially due to security concerns, CGN is blacklisted by the U.S.—and the Czech

2318 - Jan Lopatka, "Czechs put off decision on building new nuclear plants", *Reuters*, 17 May 2018, see https://www.reuters.com/article/uk-czech-nuclearpower-idUKKCN1II2SD, accessed 9 April 2021.

2319 - *NEI Magazine*, "Czech Republic approves new unit for Dukovany", *Nuclear Engineering International*, 18 November 2019, see https://www.neimagazine.com/news/newsczech-republic-approves-new-unit-for-dukovany-7513325/, accessed 9 April 2021.

2320 - Ibidem; and *NIW*, "Briefs - Czech Republic", *Nuclear Intelligence Weekly*, 15 November 2019.

2321 - *NEI Magazine*, "ČEZ applies to build new nuclear units at Dukovany", 30 March 2020, see https://www.neimagazine.com/news/newscez-applies-to-build-new-nuclear-units-at-dukovany-7844971/, accessed 9 April 2021.

2322 - Gary Peach, "Prague Announces 70% Financing for Dukovany", *Nuclear Intelligence Weekly*, 5 June 2020.

2323 - Phil Chaffee, "Newbuild: Prague Advances Dukovany Plans", *Nuclear Intelligence Weekly*, 1 May 2020.

2324 - Jan Lopatka and Jason Hovet, "Three companies vie to build new Czech nuclear plant", *Reuters*, 30 November 2022, see https://www.reuters.com/business/energy/cez-gets-3-initial-bids-build-new-unit-dukovany-nuclear-plant-2022-11-30/, accessed 5 June 2023.

2325 - *NEI Magazine*, "Czech Trade Ministry's Dukovany tender proposals spark controversy", 29 March 2021, see https://www.neimagazine.com/news/newsczech-trade-ministrys-dukovany-tender-proposals-spark-controversy-8633315, accessed 2 August 2023.

Parliament delayed a final decision as the opposition demanded the Rosatom design also be removed.[2326] Subsequently, the government cabinet unanimously approved the resolution and then-Deputy Prime Minister Karel Havlícek confirmed that security clearances would only be given to suppliers from France, South Korea and the U.S.[2327]

In March 2022, ČEZ subsidiary Elektrarna Dukovany II launched a newbuild tender for up to 1.2 GW. The three pre-qualified vendors—EDF, KEPCO subsidiary Korea Hydro & Nuclear Power (KHNP) and Westinghouse—submitted initial bids in November 2022. Final bids are expected in September 2023, with contracts to be finalized the following year. The expectation is that testing of the new units would begin in 2036. Estimations made in 2020 place project costs at around CZK160 billion (US$$_{2020}$6.9 billion).[2328] Given that only Westinghouse's AP-1000 would fit the capacity constraint, some speculations around bid design to strengthen U.S.-Czech relations (recently reinforced by the announced purchase of F-35 fighter jets) arose. However, KEPCO is apparently offering the lowest price and is willing to cooperate with Plzeň-based Škoda JS for turbine manufacturing.[2329]

There has been an ongoing dispute between Westinghouse and KHNP concerning intellectual property rights that led to Westinghouse filing for a lawsuit in October 2022 accusing KHNP of copying technology for its APR-1400 from an earlier design owned by Westinghouse (see Poland Focus). KHNP said it had filed the necessary documents to export nuclear technology to the Czech Republic on time, but they were rejected by the U.S. Department of Energy on the ground that "U.S. persons" must submit such applications, pointing towards Westinghouse. Whether KHNP can actually export nuclear technology to the Czech Republic thus depends on the outcome of the ongoing lawsuit—which in turn might have implications for KHNP's plans in Saudi Arabia and elsewhere.2330

In July 2022, the European Commission launched a state aid review of the project, which will look at the three government support mechanisms, namely:

- a low-interest repayable State loan expected to cover 100% of the construction costs (approximately €7.5 billion [US$$_{2023}$8.2 billion];
- a power purchase agreement between EDU II and a State-owned company for the lifetime of the project (60 years)—according to the Czech authorities, this would lower the power purchase price and allow for price adaptations every 5 years; and
- a mechanism to protect the ČEZ Group and the State in case certain unforeseen events occur (e.g. if the Czech law changes and makes the realisation of the project impossible).[2331]

2326 - *NIW*, "Czech Parliament Delays Dukovany", *Nuclear Intelligence Weekly*, 12 February 2021.

2327 - Phil Chaffee and Gary Peach, "Prague Excludes Rosatom From Dukovany II", *Nuclear Intelligence Weekly*, 23 April 2021.

2328 - Jan Lopatka and Jason Hovet, "Three companies vie to build new Czech nuclear plant", *Reuters*, 30 November 2022, op. cit.; and NRR, "Opinion of the Czech Fiscal Council concerning the development of public sector finances and the set-up of fiscal and budgetary policy", Národní rozpočtová rada/Czech Fiscal Council, 3 June 2020, see https://www.rozpoctovarada.cz/wp-content/uploads/2020/06/Opinion-of-the-Czech-Fiscal-Council-of-3rd-June-2020-No_4_2020.pdf, accessed 2 August 2023.

2329 - Krzysztof Dębiec, "Czech nuclear showdown enters final straight", Ośrodek Studiów Wschodnich/Centre for Eastern Studies, March 2023, see https://www.osw.waw.pl/sites/default/files/OSW%20Commentary%20500.pdf, accessed 26 July 2023.

2330 - *NEI Magazine*, "US stalls South Korea's NPP export plans", *Nuclear Engineering International*, 11 April 2023, see https://www.neimagazine.com/news/newsus-stalls-south-koreas-npp-export-plans-10747925, accessed 2 August 2023.

2331 - European Commission, "State Aid: Commission opens in-depth investigation into Czech support for new nuclear power plant in Dukovany", Press Release, 30 June 2022, see https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4244, accessed 26 July 2023.

The Commission will review "the appropriateness and proportionality" of the subsidies and their impact on the electricity market. Based on an early preliminary assessment, the Commission has "found the project necessary and considers that the aid facilitates the development of an economic activity".[2332] No official date to when the Commission would conclude was published. A similar investigation that approved state aid in Hungary via a Russian loan in 2017 had lasted for two years.[2333]

This most recent price tag (see (i) above) for the project constitutes a 25-percent increase over earlier estimates but remains very low compared to the price tag of other Gen-III reactors under construction in the E.U. and elsewhere (see Nuclear Economics and Finance and other parts of the report).

In addition to a new reactor at Dukovany, ČEZ has long been interested in building additional units at Temelín, and in March 2022 announced that they had set aside land for the construction of SMRs.[2334] Seven bidders are currently competing for the construction of a reactor at the Temelín site, with first operation scheduled for 2032 to 2035, which appears unrealistic (see chapter on SMRs). According to media reports, GE Hitachi, NuScale and Rolls-Royce are considered to have the most prospects on winning the contract.[2335] In February 2023, ČEZ announced further potential sites for SMR construction post-2035 at the current sites of coal power plants Dětmarovice and Tušimice.[2336]

In June 2022, in response to ongoing sanctions against Russian assets, ČEZ Group purchased Škoda JS—an originally Czech nuclear service company—from OMZ, a Russian engineering group controlled by Gazprombanka.[2337] Škoda JS had been acquired together with two other former Škoda Holding subsidiaries by OMZ in 2004.[2338] With the acquisition by ČEZ finalized in November 2022[2339], the company has now been removed from U.S. sanction lists where it had been included due to its former owners.[2340] Further, through the acquisition of Škoda JS, ČEZ increased its prior share of 17.39 percent in the ÚJV Řež research facility to 69.85 percent.[2341]

2332 - Ibidem.

2333 - Kamen Kraev, "European Commission To Investigate State Support Scheme For New Dukovany Plant", *NucNet*, 1 July 2022, see https://www.nucnet.org/news/european-commission-to-investigate-state-support-scheme-for-new-dukovany-plant-7-5-2022, accessed 2 August 2023.

2334 - *WNN*, "Space allocated at Temelín for future SMRs", *World Nuclear News*, 1 April 2022, see https://world-nuclear-news.org/Articles/Space-allocated-at-Temelin-for-future-SMR, accessed 7 July 2022.

2335 - David Tramba, "Modulární reaktor do Temelína dodá jeden ze sedmi uchazečů. Který z nich má šanci uspět?", *Ekonomoický deník* (in Czech), 21 January 2023, see https://ekonomickydenik.cz/modularni-reaktor-do-temelina-doda-jeden-ze-sedmi-uchazecu-ktery-z-nich-ma-sanci-uspet/, accessed 26 July 2023.

2336 - Krzysztof Dębiec, "Czech nuclear showdown enters final straight", Centre for Eastern Studies, March 2023, op. cit.

2337 - *WNN*, "ČEZ buys Škoda JS from Russian owners", *World Nuclear News*, 20 June 2022, see https://www.world-nuclear-news.org/Articles/CEZ-buys-supplier-Skoda-JS-from-Russian-owners, accessed 20 June 2022.

2338 - *Clarion Energy*, "OMZ – Power Machines Group purchase Skoda subsidiaries", *Power Engineering*, 5 July 2004, see https://www.power-eng.com/nuclear/omz-power-machines-group-purchase-skoda-subsidiaries/, accessed 2 August 2023.

2339 - Škoda JS, "Yesterday, ČEZ finally took over ŠKODA JS, a major Czech company focusing on nuclear service and engineering", Press Release, 25 November 2022, see https://www.skoda-js.cz/press/yesterday-cez-finally-took-over-skoda-js/, accessed 7 November 2023.

2340 - Škoda JS, "ŠKODA JS Removal from the U.S. OFAC's Sanctions List", Press Release, 16 May 2023, see https://www.skoda-js.cz/press/skoda-js-removal-from-the-u-s-ofacs-sanctions-list/, accessed 7 November 2023.

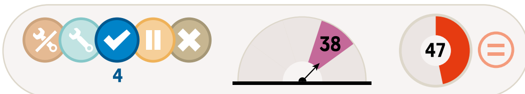
2341 - Michal Hudec, "Slovak nuclear plants serviced by Gazprom-linked company", *Euractiv*, 5 April 2022, see https://www.euractiv.com/section/politics/short_news/slovak-nuclear-plants-serviced-by-gazprom-linked-company/, accessed 8 July 2022; and CEZ Group, "2022 Annual Financial Report—I. Activity Report", 2023, see https://www.cez.cz/webpublic/file/edee/ospol/fileexport/investori/vz-2022/cez-group-annual-financial-report-2022-pdf.pdf, accessed 7 November 2023.

With this acquisition, Czech companies are now actively involved in several local nuclear power plant component suppliers, such as Sigma Group, a supplier of pumps used in nuclear power plants. However, fittings manufacturer Arako is still owned by Rosatom, and Chinese-owned machinery company Žd'as had been generating 20 percent of its turnover from sales to Russia. [2342]

In 2022, the Czech Republic generated a total 85.91 TWh of electricity, of which over 43 percent were attributed to coal, around 8 percent to natural gas, and 36 percent to nuclear power. Just shy of 1 percent were generated by "other fossil fuels". Bioenergy contributed 6 percent of electricity generation while solar and hydro accounted for only 3 percent and 2 percent, respectively. Wind power contributed less than 1 percent.[2343]

In its most recent National Energy and Climate Plan (NECP) of 2019, 2040 targets envisioned a reduction of the share of coal generation to 11–21 percent, the increase of nuclear to 46-58 percent and a share of renewable electricity generation of a maximum of 25 percent. Natural gas was also to play a role (contributing 5–15 percent).[2344] An updated version of the NECP was due to be submitted to the European Commission by end-June 2023, but this has so far not occurred (as of writing in August 2023).[2345] In 2022 however, the newly elected Government had signaled prospects of a coal phase-out by 2033 and emphasized their willingness to expand nuclear capacities.[2346]

Hungary



Hungary has one operating nuclear power plant at Paks where four VVER-440 v213 reactors provided 14.95 TWh or 47 percent of the country's electricity in 2022. The production volume has been in this range for several decades. The nuclear share in the national power mix peaked at 53.6 percent in 2014. The reactors started operation between 1982 and 1987 and have been the subject of engineering works to enable their operation for up to 50 years (compared to their initial 30-year license). The first unit received permission to operate for another 20 years in 2012, the second in 2014, the third in 2016, and the fourth in December 2017, enabling operation until the mid-2030s.

In Hungary, renewable capacities have been increasing over the past decade, driven by the expansion of solar from just 1 MW in 2016 to over 3 GW in 2022. By 2030, solar capacity is

2342 - Krzysztof Dębiec, "Czech nuclear showdown enters final straight", Centre for Eastern Studies, March 2023, op. cit.

2343 - Ember, "Ember Electricity Data Explorer,—Czechia electricity generation by source", 2023, see https://ember-climate.org/data/data-tools/data-explorer/, accessed 2 August 2023.

2344 - European Commission, "National Energy and Climate Plan of the Czech Republic", November 2019, see https://energy.ec.europa.eu/system/files/2020-03/cs_final_necp_main_en_0.pdf, accessed 2 August 2023.

2345 - European Commission, "National Energy and Climate Plans", Energy and climate governance and reporting, 2 August 2023, see https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en, accessed 2 August 2023.

2346 - Jason Hovet and Robert Muller, "New Czech government sees coal exit by 2033, backs nuclear power", *Reuters*, 7 January 2022, see https://www.reuters.com/markets/commodities/new-czech-government-sees-coal-exit-by-2033-backs-nuclear-power-2022-01-07/, accessed 2 August 2023.

envisioned at 6 GW, and at 12 GW by 2040. Wind power however seems to be fully neglected, stagnating for over a decade at around 320 MW.[2347]

Notwithstanding this development, in July 2022, the government announced it would put forward economic and technical plans to further extend the operating lives of the existing nuclear reactors by up to 20 years.[2348] In early December 2022, this decision was approved with an overwhelming majority in parliament (170 votes in favor, 8 against, 1 abstention) and provides a legal framework for Paks lifetime extension well into the 2050s.[2349]

For over a decade, plans have been discussed and developed to build additional nuclear power plants. In March 2009, the Parliament approved a government decision-in-principle to build additional reactors[2350] and a tender was prepared according to E.U. rules. In 2014, the Paks II project consisting of two 1,200-MW reactors was suddenly awarded to Rosatom without reference to the public tender, with Russia financing 80 percent of the project in loans.[2351] In February 2017, during a visit to Hungary, President Putin confirmed that Russia was even willing to fund 100 percent of the estimated €12.5 billion (US$$_{2017}$14.1 billion) investment. The original Russian-Hungarian bilateral financing agreement consisted of a €10 billion (US$$_{2023}$11 billion) loan to the Hungarian state, to be repaid starting in 2026, irrespective whether the project would be online at that time. Hungary itself would have to invest 20 percent or €2.5 billion (US$$_{2023}$2.5 billion) into the project. Then in April 2021, the loan terms were revised so that Hungary would start repaying the loan in 2031, five years later than originally agreed.[2352] It had been noted in 2020 that the government had ceased pressing for the project to proceed. Rosatom had been awarded the project at a fixed price contract that "might no longer be favorable", while in Hungary cheaper solar deployment is rapidly highlighting the high costs of potential electricity produced by Paks II, which would be borne by the taxpayers.[2353]

Legal Challenges to State Aid for Paks II

In November 2016, the European Commission cleared the award of the contract to Rosatom of any infringement on its procurement rules,[2354] and in March 2017, it also approved the financial

2347 - IEA, "Hungary 2022 Energy Policy Review", International Energy Agency, September 2022, p. 70, see https://iea.blob.core.windows.net/assets/9f137e48-13e4-4aab-b13a-dcc90adf7e38/Hungary2022.pdf, accessed 28 July 2023.

2348 - *NEI Magazine*, "Key licences issued for Paks-II", *Nuclear Engineering International*, 6 July 2022, see https://www.neimagazine.com/news/newskey-licences-issued-for-paks-ii-9829343/, accessed 13 July 2022.

2349 - Anita Komuves, "Hungary parliament approves lifespan extension of Paks nuclear power plant", *Reuters*, 7 December 2022, see https://www.reuters.com/world/europe/hungary-parliament-approves-lifespan-extension-paks-nuclear-power-plant-2022-12-07/, accessed 27 July 2023.

2350 - PAKS II, "Background of the Project", Undated, see https://www.paks2.hu/web/paks-2-en/background-of-the-project; and *WNN*, "Hungarian parliament approves Paks expansion", *World Nuclear News*, 31 March 2009, see https://www.world-nuclear-news.org/Articles/Hungarian-parliament-approves-Paks-expansion; both accessed 28 July 2023.

2351 - Csaba Tóth, "Hungary, Russia sign Paks II implementation agreements", *The Budapest Beacon*, 9 December 2014, see https://budapestbeacon.com/hungary-russia-sign-3-implementation-agreements-paks-ii/, accessed 27 July 2023.

2352 - Marton Dunai, "CORRECTED-Hungary gets 5-year payment delay on Russian-led nuclear plant project", *Reuters*, 29 April 2021, see https://www.reuters.com/article/hungary-nuclearpower-russia-financing-idINL8N2MM8SW, accessed 27 July 2023.

2353 - Gary Peach, "Hungary: Exorbitant Costs, Solar Energy Remove Luster From Paks II", *Nuclear Intelligence Weekly*, 22 May 2020.

2354 - Philip Blenkinsop, "EU drops part of reservation to Hungary's Paks nuclear project", *Reuters*, 18 November 2016, see https://www.reuters.com/article/us-hungary-nuclearpower-eu-idUSKBN13D0QN, accessed 27 July 2023.

package for Paks II.[2355] However, in February 2018 the Austrian Government challenged the validity of the decision.[2356] In November 2022, the European General Court ruled that because Hungary's state aid for the Paks II project "only concerns the investment costs for two new reactors to replace the four old reactors [...] and no operating aid so foreseen, the impact on the energy market is limited", setting precedence for state-financed nuclear newbuild projects in Europe. The legal challenge had been supported by the Luxembourg Government, while the Czech Republic, France, Hungary, Poland, Slovakia, and the United Kingdom stood with the Commission.[2357] In April 2023, the Hungarian Government and Rosatom updated the delivery contract reportedly saying that "even without the war and sanctions 'life and the technological situation have changed so much'" since the initial signature. Details on the contract remain unpublished.[2358] According to the government, the amendments were approved by the European Commission in May 2023.[2359]

Opposition Against the Construction License for Paks II

In March 2017, the Hungarian Atomic Energy Authority (HAEA) issued the site license for the new construction.[2360] However, since then, there have been increasing concerns over the impact of hotter summers on the cooling water availability due to higher water temperatures from the Danube River, especially if both Paks I and II are in operation. Within the Environmental Impact Assessment (EIA) process the solution to this problem was to reduce output from the plants when cooling water availability was limited, which would affect the economics of the project and the demand-supply grid balance.[2361]

In addition, a 2021-report published by the Austrian Federal Environmental Agency found that the Dunaszentgyörgy-Harta seismic fault passes through the Paks II site. According to the report, the fault is both active and capable. The assessment concludes that "The Paks II site should therefore be deemed unsuitable".[2362] The Hungarian authorities, responding to the publication of the Austrian report, stated that the licensing process had not found any issues that indicated that the site was unsuitable.[2363]

2355 - European Commission, "Commission Decision (EU) 2017/2112 of 6 March 2017 on the measure/aid scheme/State aid SA.38454—2015/C (ex 2015/N) which Hungary is planning to implement for supporting the development of two new nuclear reactors at Paks II nuclear power station", L 317/45, *Official Journal of the European Union*, 6 March 2017, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017D2112, accessed 27 July 2023.

2356 - *WNN*, "Austria takes EC to court over Paks decision", *World Nuclear News*, 23 February 2018, see https://www.world-nuclear-news.org/NP-Austria-takes-EC-to-court-over-Paks-decision-2302184.html, accessed 27 July 2023.

2357 - Nikolaus J. Kurmayer, "Austria loses EU court case against Hungarian nuclear power plant", *Euractiv*, 1 December 2022, see https://www.euractiv.com/section/energy/news/austria-loses-eu-court-case-against-hungarian-nuclear-power-plant/, accessed 14 January 2023.

2358 - *WNN*, "Hungary and Russia amend Paks II nuclear project agreement", *World Nuclear News*, 12 April 2023, see https://www.world-nuclear-news.org/Articles/Hungary-and-Russia-amend-Paks-2-nuclear-project-ag, accessed 13 April 2023.

2359 - David Dalton, "European Commission Has Approved Changes To Paks 2 Nuclear Contracts With Russia, Says Foreign Minister", *NucNet*, 26 May 2023, see https://www.nucnet.org/news/european-commission-has-approved-changes-to-paks-2-nuclear-contracts-with-russia-says-foreign-minister-5-5-2023, accessed 2 August 2023.

2360 - *NIW*, "Briefs – Hungary", *Nuclear Intelligence Weekly*, 31 March 2017.

2361 - Gary Peach, "Five Years on, Hungary's Paks Expansion Stumbles Along", *Nuclear Intelligence Weekly*, 8 February 2019.

2362 - Kurt Decker and Esther Hintersberger, "NPP Paks II—Paleoseismological Assessment of the Siting Report and the Site License with Respect to Fault Capability—Executive Summary", REP-0759, Umweltbundesamt/Environment Agency Austria, 2021, see https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0759bfz.pdf, accessed 27 July 2023.

2363 - Eszter Zalan, "Hungary's nuclear power plant expansion unnerves Austria", *EUobserver*, 7 June 2021, see https://euobserver.com/climate/152035, accessed 19 June 2021.

Process Continues Despite Concerns

In June 2019, a "solemn ceremony" was held with representatives of Rosatom to mark the start of the erection of buildings at the site[2364] and in October 2019, Rosatom submitted the project technical documents. On 30 June 2020, Paks II Ltd. submitted the construction license application to the HAEA. The regulator started its assessment procedure the next day and had 12 months to make its views known.[2365] That period was extended by an additional three months in May 2021.[2366] If all went according to plan, site preparation would take an additional 18 months, therefore formal construction was to start in mid-2022, some six years after the Hungarian and Russian Government signed the corresponding intergovernmental agreements. That did not happen, and in October 2021, following IAEA feedback, HAEA announced that it needed more time "to fully verify all requirements," without giving an updated timeline.[2367]

Despite the economy wide sanctions against Russian companies, Paks II is proceeding, as nuclear energy is not, as of end of July 2023, subject to E.U. sanctions. In May 2022, following Rosatom reassurances, Hungarian authorities seemed confident that "in terms of technology they are able to complete the project".[2368] In July 2022, the Government announced that further site preparation licenses had been awarded by HAEA,[2369] and in August 2022, construction licenses for two new VVER 1200 reactors were granted.[2370]

Following talks between Minister Peter Szijjártó and Rosatom's Director General Alexei Likhachev in December 2022, the Hungarian government announced that preparatory work at Paks II would begin in July 2023.[2371] On 5 July 2023, Rosatom announced that work had started to build a groundwater cut-off and preparatory work onsite was ongoing.[2372] As of July 2023,

2364 - JSC ASE, "The first construction and installation work launches at the construction base of the Paks-2 NPP (Hungary)", Press Release, Rosatom, 21 June 2019, see https://www.rosatom.ru/en/press-centre/news/the-first-construction-and-installation-work-launches-at-the-construction-base-of-the-paks-2-npp-hun/?, accessed 27 July 2023.

2365 - HAEA, "Paks II. Ltd. submitted the construction license application to the HAEA", Hungarian Atomic Energy Authority, 30 June 2020.

2366 - HAEA, "Hirdetmény közzététele az ügyintézési határidő meghosszabbításáról a paksi telephelyen létesítendő 5. és 6. atomerőművi blokkok létesítési engedélyezési eljárásában", Hungarian Atomic Energy Authority, 19 May 2021, see https://www.haea.gov.hu/web/v3/oahportal.nsf/web?OpenAgent&article=news&uid=4346A8D52E23910EC12586DA0023F45A, accessed 27 July 2023.

2367 - *WNN*, "Paks II construction licence delayed", *World Nuclear News*, 1 October 2021, see https://www.world-nuclear-news.org/Articles/Paks-II-construction-licence-delayed, accessed 3 October 2021; and HAEA, "Announcement of the Hungarian Atomic Energy Authority", 13 October 2021, see http://www.oah.hu/web/v3/HAEAportal.nsf/web?OpenAgent&article=news&uid=F819FBDEC81262D4C125876D00231E4B, accessed 27 July 2023.

2368 - *WNN*, "Hungary and Rosatom push ahead on Paks II nuclear project", *World Nuclear News*, 20 May 2022, see https://www.world-nuclear-news.org/Articles/Hungary-and-Rosatom-push-ahead-on-Paks-II-nuclear, accessed 13 July 2022.

2369 - *NEI Magazine*, "Key licences issued for Paks-II", *Nuclear Engineering International*, 6 July 2022, see https://www.neimagazine.com/news/newskey-licences-issued-for-paks-ii-9829343/, accessed 13 July 2022.

2370 - HAEA, "The HAEA issued the construction license to Paks II. Ltd.", Hungarian Atomic Energy Authority, 26 August 2022, see http://www.oah.hu/web/v3/HAEAportal.nsf/web?OpenAgent&article=news&uid=273E525123362584C12588AA002F9FE1; and *WNN*, "Construction licence issued for Paks II", 26 August 2022, see https://www.world-nuclear-news.org/Articles/Construction-licence-issued-for-Paks-II; both accessed 27 July 2023.

2371 - *WNN*, "Hungary says Paks II work to start in July", *World Nuclear News*, 7 June 2023, see https://world-nuclear-news.org/Articles/Hungary-says-Paks-II-work-to-start-in-July, accessed 15 June 2023.

2372 - Rosatom, "ROSATOM started the first phase of construction of Paks II NPP units", Press Release, 5 July 2023, see https://rosatom.ru/en/press-centre/news/rosatom-started-the-first-phase-of-construction-of-paks-ii-npp-units/, accessed 27 July 2023.

official construction start is expected by mid-2024,[2373] both reactors are to come online by 2032 and operate for 60 years.[2374] In 2014, the first unit was scheduled to start up in 2023.[2375]

Hungary's energy supply heavily depends on Russia.[2376] With its continued blocking of E.U. sanctions against Russia, especially in the nuclear sector, Hungary is being rewarded by continued supply of Russian gas mostly via the Turkstream pipeline.[2377] "We had to act forcefully against the listing of Rosatom or Rosatom officials," Szijjarto commented on negotiations of the 10th E.U. sanction package in February 2023. "Any sanctions on nuclear energy or Rosatom would harm Hungary's fundamental national interests."[2378] Hungary's dependence on Russian nuclear fuel became remarkably evident in April 2022, when fresh nuclear fuel was flown from Russia following the awarding of a special permit to bypass the E.U. airspace closure to Russian aircraft.[2379]

Despite the Commission's green light and the successful Hungarian resistance against sanctions in the nuclear sector, the Paks-II project is facing some difficulties. For example, German company Siemens was supposed to deliver parts of control-command systems for Paks II together with French Framatome, but export grants, necessary due to dual-use legislation, are reportedly being withheld by the German government.[2380] The Hungarian government is threatening Siemens with the cancellation of other orders, e.g. for locomotives, and is seeking to focus on Framatome as major European supplier for nuclear plant components.[2381] Despite the ongoing war, the French government actively supports the involvement of French suppliers in the Paks II project, arguing that "French nuclear industry players support our European partners, and in particular Hungary, in all their efforts and in all the projects on their soil as long as they strictly respect the European framework of international sanctions.

2373 - Boldizsar Gyori and Krisztina Than, "UPDATE 1-Hungary expects first concrete poured in mid-2024 at Paks nuclear plant", Reuters, 6 July 2023, see https://www.reuters.com/article/hungary-nuclearpower-paks-idUSL8N38S2Z4, accessed 28 July 2023.

2374 - *NEI Magazine*, "Paks-II now scheduled for 2032", *Nuclear Engineering International*, 13 January 2023, see https://www.neimagazine.com/news/newspaks-ii-now-scheduled-for-2032-10515669, accessed 14 January 2023.

2375 - *WNN*, "Paks project company to be sold to state", *World Nuclear News*, 16 October 2014, see https://world-nuclear-news.org/Articles/Paks-project-company-to-be-sold-to-state, accessed 27 July 2023.

2376 - IEA, "Hungary 2022 Energy Policy Review", International Energy Agency, September 2022, see https://iea.blob.core.windows.net/assets/9f137e48-13e4-4aab-b13a-dcc90adf7e38/Hungary2022.pdf, accessed 28 July 2023.

2377 - Krisztina Than, "Hungary's foreign minister holds energy talks with Russia's premier", *Reuters*, 29 March 2023, see https://www.reuters.com/world/europe/hungarys-foreign-minister-holds-energy-talks-with-russias-premier-2023-03-29/; and Krisztina Than and Boldizsar Gyori, "Hungary agrees on option for more Russian gas shipments, oil transit fees", 11 April 2023, *Reuters*, see https://www.reuters.com/business/energy/hungary-agrees-option-more-russian-gas-shipments-oil-transit-fees-2023-04-11/; both accessed 28 July 2023.

2378 - Jason Hovet and Gergely Szakacs, "Sanctions on nuclear energy would harm Hungary's interests, minister says", *Reuters*, 22 February 2023, see https://www.reuters.com/business/energy/sanctions-nuclear-energy-would-harm-hungarys-interests-minister-says-2023-02-22/, accessed 27 July 2023.

2379 - Ashutosh Pandey, "Why EU sanctions don't include Russian nuclear industry", *Deutsche Welle*, 19 July 2023, see https://www.dw.com/en/russia-nuclear-industry-eu/a-66275352, accessed 27 July 2023.

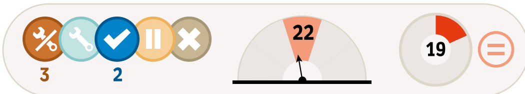
2380 - *Portfolio*, "Harmadszorra is beleszállt a német kormányba Szijjártó Péter és belengette a még szorosabb orosz együttműködést", 22 February 2023 (in Hungarian), see https://www.portfolio.hu/gazdasag/20230222/harmadszorra-is-beleszallt-a-nemet-kormanyba-szijjarto-peter-es-belengette-a-meg-szorosabb-orosz-egyuttmukodest-598634, accessed 1 March 2023; and Krisztina Than, "UPDATE 1-Germany 'blocking' equipment for Paks reactors, Hungarian minister says ", *Reuters*, 14 February 2023, see https://www.reuters.com/article/hungary-nuclear-siemens-idINL1N34U1M2, accessed 28 July 2023.

2381 - *Hungary Today*, "Government to Restrict Business Relations with Siemens", 15 May 2023, see https://hungarytoday.hu/government-to-restrict-business-relations-with-siemens/, accessed 5 June 2023.

To date, European sanctions [against Russia] do not target the nuclear industry."[2382] In March 2023, Szijjártó had suggested to bring Russian suppliers into the mix, if Framatome failed to "take over leadership of the [Franco-German] consortium".[2383] But reportedly, the Hungarian Government is currently working on sidelining Siemens to cooperate solely with Framatome.[2384] French involvement is set to further increase as EDF in late 2022 announced that an agreement had been made to acquire GE Steam Power's nuclear activities,[2385] whose subsidiary GE Hungary had won the tender to supply the turbines for Paks II in 2018[2386].

Other issues regarding transportation of components, originally planned via Ukraine, the hiring of skilled labor, and the cooperation of German, French, and Russian workers puts additional pressure on the Paks II project.[2387]

Romania



Romania has one nuclear power plant at Cernavoda, where two Canadian-designed CANDU reactors are in operation. In 2022, they provided a stable 10.2 TWh or 19.4 percent of the country's electricity.

The reactors are the only CANDU reactors operating in Europe. Construction started between 1982 and 1987, initially on five reactors. Following years-long construction interruptions, Unit 1 was completed in 1996, and Unit 2 started up in 2007, respectively 14 and 24 years after construction originally started. The two units were partly funded by the Canadian Export Development Corporation, the second also partly by the Euratom Loan Facility.

As with other ageing CANDU reactors, major refurbishment will be needed to ensure continued operation. In 2017, the plan to upgrade Unit 1 to allow for a 30-year lifetime extension was initiated upon approval from shareholders.[2388] In February 2020, the IAEA lead a Pre-SALTO (Safety Aspects of Long-Term Operation) mission onsite, identifying fifteen issues considered needing further improvement. A full SALTO mission is scheduled in 2024.[2389] In February 2022, the investment decision for the refurbishment project was approved based on an "enhanced

2382 - Jean-Baptiste Chastand, Adrien Pécout and Philippe Ricard, "Paris approves the building of Russian-led nuclear reactors in Hungary", *Le Monde*, 28 April 2023, see https://www.lemonde.fr/en/international/article/2023/04/28/in-hungary-paris-is-willing-to-help-build-russian-led-nuclear-reactor_6024637_4.html, accessed 5 June 2023.

2383 - *NEI Magazine*, "France or Russia to provide equipment to Paks-II if Germany refuses", 3 March 2023, see https://www.neimagazine.com/news/newsfrance-or-russia-to-provide-equipment-to-paks-ii-if-germany-refuses-10648100, accessed 28 July 2023.

2384 - Dániel Deme, "Government to Side-Step Siemens in Another Blow for German Industry", *Hungary Today*, 8 June 2023, see https://hungarytoday.hu/government-to-side-step-siemens-in-another-blow-for-german-industry/, accessed 28 July 2023.

2385 - *Power Technology*, "EDF signs agreement to acquire GE Steam Power's nuclear activities", 7 November 2022, see https://www.power-technology.com/news/edf-ge-steam-powers-nuclear/, accessed 2 August 2023.

2386 - *WNN*, "General Electric wins turbine contract for Paks II", *World Nuclear News*, 17 January 2018, see https://world-nuclear-news.org/Articles/General-Electric-wins-turbine-contract-for-Paks-II, accessed 2 August 2023.

2387 - Nick Thorpe, "Hungary's risky bet on Russia's nuclear power", *BBC News*, 15 December 2022, see https://www.bbc.com/news/world-europe-63964744, accessed 17 December 2022.

2388 - *NEI Magazine*, "Romania to upgrade Cernavoda 1", 5 October 2017, see https://www.neimagazine.com/news/newsromania-to-upgrade-cernavoda-1-5940262/; and SNN, "Resolution number 9 /28.09.2017 of the Extraordinary General Meeting of Shareholders of Societatea Nationala Nuclearelectrica S.A.", Societatea Nationala Nuclearelectrica S.A., 28 September 2017, see https://www.nuclearelectrica.ro/wp-content/uploads/2017/08/Hotarare-AGEA-28.09.2017-ORA-12-ENG.pdf, accessed 2 August 2023,

2389 - IAEA, "Executive Summary", International Nuclear Energy Agency, Undated, see https://www.iaea.org/sites/default/files/documents/review-missions/45_cernavoda_pre-salto_executive_summary.pdf, accessed 31 August 2023.

safety" scenario with overnight costs estimated at €1.85 billion (US$$_{2022}$2 billion) as laid out in the feasibility study.[2390]

In July 2022, a US$64 million contract, was awarded to Candu Energy—designer of Unit 1 and the original equipment manufacturer—establishing a 2.5 year mandate to "provide engineering and early procurement services for retubing work to replace key components of the reactor core: fuel channels, pressure tubes and feeders".[2391] In March 2023, the company obtained a further mandate to deliver front-end engineering services, through a US$65-million contract.[2392] The large-scale refurbishment outage was initially expected to start in 2026,[2393] and is now to be carried out in 2027–2029.[2394]

However, as the current 10-year operating license expires in 2023 and some components reach the end of their design lifetime, some refurbishment work must be implemented ahead of the full-scale outage and an intermediate regulatory solution must be found.[2395] Thus, Candu Energy was awarded a US$10.8-million contract in January 2020, to undertake engineering analysis and assessments on the fuel channels and feeders assemblies,[2396] followed by a contract in May 2022, to carry out optimization work on several fuel channels over three years.[2397]

Concerning Unit 2, Nuclearelectrica stated "Unit 2 was started up in 2007, so we can talk about the refurbishment of Unit 2 in 2037."[2398]

Various foreign companies have been involved in the attempts to revive the construction of Units 3, 4, and 5. In November 2013, Nuclearelectrica and China General Nuclear (CGN) signed

2390 - Nuclearelectrica, "The General Meeting of Shareholders has approved today the investment decision for Cernavoda NPP Unit 1 Refurbishment Project", Press Release, 23 February 2022, see https://www.nuclearelectrica.ro/2022/02/23/the-general-meeting-of-shareholders-has-approved-today-the-investment-decision-for-cernavoda-npp-unit-1-refurbishment-project/?lang=en; and Nuclearelectrica, "Refurbishment of Cernavoda NPP Unit 1", Undated, see https://www.nuclearelectrica.ro/project-development-activities/refurbishment-of-cernavoda-npp-unit-2/?lang=en; also Erns & Young SRL, "Cernavodă NPP Unit 1 Refurbishment—Project Feasibility Study", v1 version, commissioned by SN Nuclearelectrica S.A., 17 January 2022, see https://www.nuclearelectrica.ro/ir/wp-content/uploads/sites/9/2022/01/EN-2.-Executive-Summary-SNN-U1-FS-Stage-2-EY-Feasibility-Study-v1-fn-.pdf; all accessed 3 August 2023.

2391 - SNC-Lavalin, "SNC-Lavalin Advances Romanian Nuclear Refurbishment Project with $64 Million Contract Win", Press Release, 21 July 2022, see https://www.snclavalin.com/en/media/press-releases/2022/21-07-2022, accessed 4 August 2023.

2392 - SNC-Lavalin, "SNC-Lavalin Continues to Advance Romanian Nuclear Refurbishment with $65 Million Contract", Press Release, 7 March 2023, see https://www.snclavalin.com/en/media/press-releases/2023/07-03-2023, accessed 4 August 2023.

2393 - *NEI Magazine*, "Romania cancels China deal on Cernavoda but proceeds with life extension", 24 January 2020, see https://www.neimagazine.com/news/newsromania-cancels-china-deal-on-cernavoda-but-proceeds-with-life-extension-7653710/, accessed 24 May 2023.

2394 - Nuclearelectrica, "Nuclearelectrica advances Cernavoda NPP Unit 1 Refurbishment Project through new agreement with SNC-Lavalin Group", Press Release, 7 March 2023, see https://www.nuclearelectrica.ro/2023/03/07/nuclearelectrica-advances-cernavoda-npp-unit-1-refurbishment-project-through-new-agreement-with-snc-lavalin-group/?lang=en; and SNC-Lavalin, "SNC-Lavalin Continues to Advance Romanian Nuclear Refurbishment with $65 Million Contract", Press Release, 7 March 2023, see https://www.snclavalin.com/en/media/press-releases/2023/07-03-2023; both accessed 3 August 2023.

2395 - Nuclearelectrica, "Cernavoda NPP Unit 1 Refurbishment Project Feasibility Study—Stage 2 – Feasibility Study (v1 version), 2022, see https://www.nuclearelectrica.ro/ir/wp-content/uploads/sites/9/2022/01/EN-2.-Executive-Summary-SNN-U1-FS-Stage-2-EY-Feasibility-Study-v1-fn-.pdf, accessed 31 August 2023.

2396 - SNC-Lavalin, "SNC-Lavalin awarded nuclear contract in Romania to assess Cernavoda Unit 1 for continued operation", Press Release, 21 January 2020, see https://www.snclavalin.com/en/media/press-releases/2020/21-01-2020, accessed 3 August 2023.

2397 - SNC-Lavalin, "SNC-Lavalin to carry out performance optimization work for CANDU nuclear reactor in Romania", Press Release, 19 May 2022, see https://www.snclavalin.com/en/media/press-releases/2022/19-05-2022, accessed 4 August 2023.

2398 - Nuclearelectrica, "Refurbishment of Cernavoda NPP Unit 1", Undated, see https://www.nuclearelectrica.ro/project-development-activities/refurbishment-of-cernavoda-npp-unit-2/?lang=en, accessed 3 August 2023.

a letter of intent for the construction of Units 3 and 4.[2399] This was followed in November 2015 with the signing of a MoU between Nuclearelectrica and CGN for the construction, operation and decommissioning of the two units. The MoU also included agreements on investments, and remarkably, given geopolitical tensions with China, CGN was to be the majority share owner of the project with at least 51 percent of the shares.[2400]

In January 2016, the Romanian Government formally expressed support for the CGN-led project. The cost of the completion of two reactors with a 720 MW capacity each was expected to be €7.2 billion (US$$_{2016}$ 7.8 billion).[2401] However, in January 2020, the Government announced that it would cancel the deal and then Prime Minister Ludovic Orban stated that "the partnership with the Chinese company is not going to work."[2402]

In August 2019, the U.S. blacklisted CGN for allegedly stealing nuclear technology for "military uses" and added the state-owned Chinese firm and its three subsidiaries to its "entity list". The move makes it virtually impossible for American companies to supply or cooperate with the company without specific permissions.[2403] The next month, the U.S. and Romania signed a nuclear co-operation agreement.[2404]

On 9 October 2020, Adrian Zuckerman, the U.S. ambassador to Romania, said in a speech at the initialing of the intergovernmental nuclear co-operation agreement: "Now we have a great clean American company, Aecom, leading this [US]$8 billion project, with assistance from clean Romanian, Canadian and French companies."[2405] U.S. Export-Import (EXIM) Bank signed an MoU the same day with the Romanian Ministry of Economy. Three weeks later, Romania and France signed a declaration of intent for a partnership on the construction of Units 3 and 4 and the upgrade of Unit 1.[2406]

In December 2020, U.S. EXIM President and Chairman Kimberly A. Reed stated:

> The Cernavoda success comes in the aftermath of the rejection of a plan for a nuclear power entity in the People's Republic of China to undertake this project. I am happy that Romania

2399 - *NEI Magazine*, "CGN signals intent to participate in Romania's Cernavoda 3&4", 28 November 2013, see https://www.neimagazine.com/news/newscgn-signals-intent-to-participate-in-romanias-cernavoda-34, accessed 3 August 2023.

2400 - *Romania Insider*, "Romania and China seal deal for Cernavoda nuclear plant expansion", 9 May 2019, see https://www.romania-insider.com/index.php/romania-china-seal-deal-nuclear-plant; and SNN, "The signing of the Memorandum of Understanding regarding the development, construction, operation and decommissioning of Units 3 and 4 of Cernavoda NPP", Press Release, Societatea Nationala Nuclearelectrica, 10 November 2015, see https://www.nuclearelectrica.ro/2015/11/10/the-signing-of-the-memorandum-of-understanding-regarding-the-development-construction-operation-and-decommissioning-of-units-3-and-4-of-cernavoda-npp/?lang=en; both accessed 3 August 2023.

2401 - *WNN*, "Romania expresses support for China's role at Cernavoda", *World Nuclear News*, 25 January 2016, see https://www.world-nuclear-news.org/NN-Romania-expresses-support-for-China-role-at-Cernavoda-25011601.html, accessed 10 April 2021.

2402 - *NEI Magazine*, "Romania Cancels China Deal on Cernavoda but Proceeds with Life Extension", 24 January 2020, op. cit.

2403 - Felix Todd, "China nuclear firm blacklisted by US for 'unauthorised' use of tech", *NS Energy*, 15 August 2019, see https://www.nsenergybusiness.com/news/china-nuclear-us-tech/, accessed 31 August 2023; and Bureau of Industry and Security, "Addition of Certain Entities to the Entity List, Revision of Entries on the Entity List, and Removal of Entities From the Entity List", Department of Commerce, U.S. Government, Federal Register, Vol. 84, No. 157, 14 August 2019, see https://www.govinfo.gov/content/pkg/FR-2019-08-14/pdf/2019-17409.pdf, accessed 6 November 2023.

2404 - Stephanie Cooke, "Aecom to Lead $8 Billion Completion of Romania's Cernavoda-3 and -4", *Energy Intelligence*, 7 October 2020, see https://www.energyintel.com/0000017b-a7db-de4c-a17b-e7dbb8d20000, accessed 31 August 2023.

2405 - U.S. Embassy in Romania, "Ambassador Adrian Zuckerman at the DOE Intergovernmental Agreement Signing Event", 9 October 2020, see https://ro.usembassy.gov/ambassador-adrian-zuckerman-at-the-doe-intergovernmental-agreement-signing-event/, accessed 3 August 2023

2406 - *NEI Magazine*, "Romania and France to partner on Cernavoda expansion", 29 October 2020, see https://www.neimagazine.com/news/newsromania-and-france-to-partner-on-cernavoda-expansion-8206702/, accessed 29 May 2023.

> rejected Beijing's predatory financing and is working with the United States through EXIM and the U.S. Department of Energy on a better, more reliable, alternative at Cernavoda.[2407]

Since late 2021 progress was made on the preparatory phase of the project. Stage 1 started with EnergoNuclear, the project company, signing the first contract with Candu Energy, the original manufacturer of Candu technology. Under said contract, Candu Energy is to provide "engineering services for drafting and updating the necessary documentation for initiating the Project of Units CANDU 3 and 4". This phase is expected to last 24 months. Stage 2 will then begin with site preparations and was expected to last for 18–24 months,[2408] more recently estimated to take "up to 30 months"[2409]; followed by Stage 3, the construction phase, expected to last 69–78 months with commissioning of Unit 3 expected in 2030 and Unit 4 within the next year.[2410]

Romanian legislators in late 2022 introduced a draft law to allow the implementation of a "Contract for Difference" support scheme for the Cernavoda project.[2411] The law was approved by parliament in March 2023,[2412] allowing for the Support Agreement between the Romanian government and Nuclearelectrica to be signed in June 2023, paving the way for Stage 2. Through the agreement, the government commits to secure the financing of the two units. Nuclearelectrica emphasized the intention to "carry out this project in a Euro-Atlantic consortium" based on the cooperation agreement between Romanian and U.S. Governments.[2413]

In addition, Romania also intends to deploy Small Modular Reactors (SMRs), with U.S. support. In March 2019, NuScale and Nuclearelectrica signed a first MoU, to explore the potential of SMR deployment.[2414] Then, in January 2021, Nucleareletrica received a US$1.28 million grant from the U.S. Trade and Development Agency to help identify potential sites. At the time, the

2407 - EXIM, "EXIM Chairman Kimberly Reed Meets with Romania's New Interim Prime Minister Nicolae-Ionel Ciuca to Strengthen U.S.-Romania Economic Partnership and U.S. Energy and Infrastructure Export", Export-Import Bank of the United States, 10 December 2020, see https://www.exim.gov/news/exim-chairman-kimberly-reed-meets-romanias-new-interim-prime-minister-nicolae-ionel-ciuca, accessed 31 August 2023.

2408 - Nuclearelectrica, "Units 3 and 4", Undated, see https://www.nuclearelectrica.ro/project-development-activities/units-3-and-4/?lang=en, accessed 6 November 2023.

2409 - Nuclearelectrica, "Nuclearelectrica welcomes the adoption of the Law approving the signing of the Support Agreement between the Romanian State and Nuclearelectrica for the development of the National Strategic Project Units 3 and 4 of the Cernavoda NPP", Press Release, 14 March 2023, see https://www.nuclearelectrica.ro/2023/03/14/nuclearelectrica-welcomes-the-adoption-of-the-law-approving-the-signing-of-the-support-agreement-between-the-romanian-state-and-nuclearelectrica-for-the-development-of-the-national-strategic-project-u/?lang=en, accessed 31 August 2023.

2410 - Nuclearelectrica S.A., "Cernavoda - Units 3 and 4", Undated, see http://www.nuclearelectrica.ro/project-development-activities/units-3-and-4/?lang=en, accessed 30 June 2018; and Nuclearelectrica, "Nuclearelectrica announces the advancement of CANDU Units Project: Within the Preparatory Stage, Energonuclear S.A. the project company, signed the first contract, with Candu Energy", Press Release, 25 November 2021, see https://www.nuclearelectrica.ro/2021/11/25/nuclearelectrica-announces-the-advancement-of-candu-units-project-within-the-preparatory-stage-energonuclear-s-a-the-project-company-signed-the-first-contract-with-candu-energy/?lang=en, accessed 29 August 2022.

2411 - *WNN*, "Romanian government adopts draft law on Cernavoda 3 and 4", *World Nuclear News*, 21 December 2022, see https://world-nuclear-news.org/Articles/Romania-adopts-draft-law-on-Cernavoda-3-and-4, accessed 31 August 2023.

2412 - *WNN*, "Romania adopts support agreement law for Cernavoda 3 and 4", 15 March 2023, *World Nuclear News*, see https://world-nuclear-news.org/Articles/Romania-adopts-support-agreement-law-for-Cernavoda, accessed 5 June 2023.

2413 - *WNN*, "Support agreement for Cernavoda 3 and 4 signed", *World Nuclear News*, 12 June 2023, see https://world-nuclear-news.org/Articles/Support-agreement-for-Cernavoda-3-and-4-agreed; and NuclearElectrica. "Signing of the Support Agreement between the Romanian State and Nuclearelectrica for the development of the National Strategic Project Units 3 and 4 Cernavoda NPP", Press Release, 9 June 2023, see https://www.nuclearelectrica.ro/2023/06/09/signing-of-the-support-agreement-between-the-romanian-state-and-nuclearelectrica-for-the-development-of-the-national-strategic-project-units-3-and-4-cernavoda-npp/?lang=en; both accessed 3 August 2023.

2414 - Nuclearelectrica, "NuScale and Romanian Energy Company Sign Agreement to Explore SMRs for Romania", 19 March 2019, see https://www.nuclearelectrica.ro/2019/03/19/nuscale-and-romanian-energy-company-sign-agreement-to-explore-smrs-for-romania/?lang=en, accessed 4 August 2023.

Agency described that their technical assistance (Sargent & Lundy) would "identify a short list of SMR-suitable sites, assess SMR technology options and develop site-specific licensing roadmaps."[2415] In November 2021, Nucleareletrica signed a "teaming agreement" with U.S. vendor NuScale to build a 462 MW six module facility at former coal plant Doiceşti in Romania "as soon as 2027/2028".[2416] Talks continued through 2022 and 2023, allowing some developments, including the signing of an MoU in May 2022 between NuScale, Nucleareletrica, and E-Infra, the owner of the former coal plant site, to conduct engineering studies, technical reviews, and licensing and permitting activities at the Doiceşti site.[2417] Most notably, in September 2022, Nucleareletrica and Nova Power & Gas launched their joint venture RoPower Nuclear SA, the project company tasked with "deploying the first NuScale VOYGR-6 (462 MWe) power plant in Romania this decade" at Doiceşti,[2418] and in late December 2022, NuScale and RoPower inked the contract for Front-End Engineering and Design (FEED) work, expected to last eight months.[2419] In June 2022, the U.S. government had announced a US$14 million grant for the FEED study.[2420]

During the 2023 Japanese G7 summit, the Japanese, South Korean, UAE and U.S. governments announced public-private commitments to invest a total of up to US$275 million into the Romanian NuScale project. Further, the International Development Finance Corporation (DFC) and the U.S. EXIM Bank would consider financial support of up to US$1 and US$3 billion[2421], respectively. NuScale CEO John Hopkins hopes that "public private partnerships [will help] deploy our leading SMR technology as soon as 2029".[2422] Note that the project end date has

2415 - USTDA, "USTDA Supports Civil Nuclear Energy in Romania", Press Release, U.S. Trade and Development Agency, 14 January 2021, see https://ustda.gov/ustda-supports-civil-nuclear-energy-in-romania/, and *WNN*, "US grant made for Romanian SMR siting assessment", *World Nuclear News*, 14 January 2021, see https://www.world-nuclear-news.org/Articles/US-grant-for-Romanian-SMR-siting-assessment; both accessed 4 August 2023.

2416 - Phil Chaffee, "Newbuild: Romania Talks of Building 'Europe's First SMR'", *Nuclear Intelligence Weekly*, 5 November 2021; and Nuclearelectrica, "NuScale and Nuclearelectrica Reach Agreement at COP26 to Initiate the Deployment of the First Small Modular Reactor in Europe", Press Release, 4 November 2021, see https://www.nuclearelectrica.ro/2021/11/04/nuscale-and-nuclearelectrica-reach-agreement-at-cop26-to-initiate-the-deployment-of-the-first-small-modular-reactor-in-europe/?lang=en, accessed 4 August 2023.

2417 - Nuclearelectrica, "Nuclearelectrica, NuScale & E-Infra sign Memorandum of Understanding to deploy NuScale's SMR technology on the first SMR site location in Romania", Press Release, 24 May 2022, see https://www.nuclearelectrica.ro/2022/05/24/nuclearelectrica-nuscale-e-infra-sign-memorandum-of-understanding-to-deploy-nuscales-smr-technology-on-the-first-smr-site-location-in-romania/?lang=en; and NuScale, "NuScale Power Signs Agreement with Nuclearelectrica and Owner of Preferred Site for First SMR Site in Romania", Press Release, 23 May 2023, see https://www.nuscalepower.com/en/news/press-releases/2022/nuscale-signs-agreement-with-nuclearelectrica-and-owner-of-preferred-site-for-first-smr-in-romania; both accessed 4 August 2023.

2418 - Nuclearelectrica, "Nuclearelectrica SA and Nova Power & Gas SRL launch RoPower Nuclear SA, the project company for the development of small modular reactors in Romania", Press Release, 27 September 2022, see https://www.nuclearelectrica.ro/2022/09/27/nuclearelectrica-sa-and-nova-power-gas-srl-launch-ropower-nuclear-sa-the-project-company-for-the-development-of-small-modular-reactors-in-romania/?lang=en, accessed 4 August 2023.

2419 - Nuclearelectrica, "NuScale Power and RoPower Announce Signing of the Contract for Phase 1 of Front-End Engineering and Design Work for First SMR Power Plant in Romania", Press Release, 4 January 2023, see https://www.nuclearelectrica.ro/2023/01/04/nuscale-power-and-ropower-announce-signing-of-the-contract-for-phase-1-of-front-end-engineering-and-design-work-for-first-smr-power-plant-in-romania/?lang=en, accessed 4 August 2023.

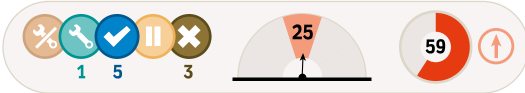
2420 - *Balkan Green Energy News*, "Romania on track to become first country with SMR nuclear power plant", 25 February 2023, see https://balkangreenenergynews.com/romania-on-track-to-become-first-country-with-smr-nuclear-power-plant/; The White House, "Fact Sheet: President Biden and G7 Leaders Formally Launch the Partnership for Global Infrastructure and Investment", Press Release, U.S. Government, 26 June 2023, see https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/26/fact-sheet-president-biden-and-g7-leaders-formally-launch-the-partnership-for-global-infrastructure-and-investment/; both accessed 4 August 2023.

2421 - *Nuclear Newswire*, "EXIM signals interest in Romanian nuclear project", American Nuclear Society, 16 November 2022, see https://www.ans.org/news/article-4502/exim-signals-interest-in-romanian-nuclear-project/, accessed 3 August 2023.

2422 - *Nuclear Newswire*, "$275 Million for NuScale VOYGR deployment in Romania announced", American Nuclear Society, 24 May 2023, see https://www.ans.org/news/article-5039/275-million-for-nuscale-voygr-deployment-in-romania-unveiled/, accessed 5 June 2023.

already been pushed forward by one year compared to 2021 plans, while design certification has yet to be obtained and actual construction work has yet to begin.

Slovakia



In Slovakia, Slovenské Elektrárne (SE), majority owned by Czech and Italian utilities, operates two nuclear sites, Jaslovské Bohunice, which houses two operating VVER-440 v213 units, and Mochovce, which has two similar reactors. Their production was a stable 14.8 TWh that in 2022 corresponded to a record of over 59 percent of the country's electricity. Like Hungary, in March 2022, Slovakia has resorted to an exceptional permission to fly in fresh nuclear fuel from Russia as a result of the war in Ukraine and insecurity of the railways in Ukraine.[2423]

The country has three permanently closed reactors at the Bohunice site. The A-1, a small 92-MW unit which started operation in 1972 and was closed in 1977 following several accidents. The other two VVER-440 v230 reactors were closed in 2006 and 2008 respectively as part of the agreement to join the European Union in 2004[2424] (for more information see Decommissioning Status Report).

The operational Units 3 and 4 of the Bohunice plant (collectively referred to as Bohunice V2 and both operational since 1985) underwent an extensive modernization program from 2000 to 2010 that included capacity uprates from 440 to 505 MWe (gross). Capacities of Units 1 and 2 of the Mochovce plant, that began operation in 1998, and 2000, respectively, were also uprated, from 440 to 470 MWe (gross).[2425] SE plans to operate Bohunice-3 and -4 to 2044 and 2045, respectively, and Mochovce-1 and -2 until 2058 and 2060, respectively.[2426]

In April 2006, the Italian national utility Enel (Ente Nazionale per l'Energia Elettrica) finalized the acquisition of a 66-percent stake in SE and, as part of its bid, committed to invest around €2 billion ($\text{US\$}_{2006}$2.5 billion) between 2006 and 2013,[2427] including completion of Mochovce-3 and -4, whose construction originally began in January 1985 and had been halted in 1993.[2428] The State of Slovakia holds the remaining 34 percent into SE. In February 2007, SE announced that Enel had agreed to invest €1.8 billion ($\text{US\$}_{2007}$2.6 billion)[2429] into the completion of the

2423 - Michal Hudec, "Russian plane with nuclear fuel landed in Slovakia", *Euractiv*, 2 March 2022, see https://www.euractiv.com/section/politics/short_news/russian-plane-with-nuclear-fuel-landed-in-slovakia/, accessed 8 July 2022.

2424 - Euractiv, "Slovakia seeking delay in nuclear plant closure", 8 April 2005, see https://www.euractiv.com/section/enlargement/news/slovakia-seeking-delay-in-nuclear-plant-closure/, accessed 7 August 2023.

2425 - Ludovit Kupca, "Long term operation of Bohunice NPP", presented at the 4th International Conference on Nuclear Power Plant Life Management, 23 October 2017, see https://www.iaea.org/publications/13640/nuclear-power-plant-life-management?supplementary=91871, accessed 12 September 2023.

2426 - GRS, "Nuclear energy in Slovakia", Gesellschaft für Anlagen- und Reaktorsicherheit, 2 March 2023, see https://www.grs.de/en/nuclear-energy-slovakia-02032023, accessed 12 September 2023.

2427 - Enel, "Enel: Acquisition of 66% of Slovenske Elektrarne completed", Press Release, 28 April 2006, see https://www.enel.com/media/explore/search-press-releases/press/2006/04/enel-acquisition-of-66-of-slovenske-elektrarne-completed, accessed 5 August 2023.

2428 - IAIA-PRIS, "Reactor Details–Mochovce-3", as of 15 April 2019. This date was later changed, and as of July 2023 construction suspension is indicated as 27 January 1990. PRIS, "PRIS—Country Statistics—Mochovce-3", IAEA, 22 July 2023, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=544 accessed 23 July 2023.

2429 - *WNN*, "Contracts signed for completion of Mochovce", *World Nuclear News*, 16 June 2009, see https://www.world-nuclear-news.org/NN-Contracts_signed_for_completion_of_Mochovce-1606094.html, accessed 5 August 2023.

reactors to be finalized by 2012.[2430] In June 2010, construction of Mochovce-3 and -4 was reintroduced in IAEA's booklet "Nuclear Power Reactors in the World", and the following, 2011 booklet edition, the units were expected to generate power in 2012 and 2013 respectively.[2431]

By March 2012, commercial operation initially scheduled for the end of 2012 was already delayed by one year, and by December 2012, Enel was requesting €800 million (US$$_{2012}$1 billion) in supplementary funding and a revision of the project timeline. The Slovak Government viewed the proposed spending as "absolutely unacceptable"[2432] and it took until August 2013 for it to approve a budget increase of €260 million (US$$_{2013}$345 million). Eventually, in November 2014, SE shareholders agreed to raise the project's budget by a further €800 million (US$$_{2014}$1 billion) to €4.6 billion (US$$_{2014}$6 billion), with the Minister of Economy attributing the additional cost to the implementation of post-Fukushima safety requirements, and "inefficiencies".[2433]

However, a few months earlier, Enel had announced it was seeking to sell its share in SE.[2434] The bidding process was hindered by a further dispute with the Slovak Government who indicated in April 2015 that it would "actively obstruct" the sale as long as the two Mochovce units were not commissioned.[2435] In December 2015, Czech holding EPH (Energeticky a Prumyslovy Holding) was revealed as the bid winner, with a preliminary price of €750 million (US$$_{2015}$832 million). Under the deal, Enel got €150 million (US$$_{2015}$166 million) in the first stage, and EPH received a stake of 33 percent in SE (via a newly created joint company), the remaining share and final price to be agreed one year after Mochovce is completed.[2436] An MoU was also established between Enel and the Ministry of Economy in December 2015, under which the parties committed to negotiate "in good faith" a possible increase of the State's share upon completion of the Mochovce units; to amend the shareholders' agreement to strengthen the Ministry's position as minority shareholder; and to "a number of principles" aimed at insuring the completion and commissioning of the two reactors.[2437] The MoU was partly introduced as amendment to the shareholders' agreement in February 2016; and in July 2016, the first phase of EPH's buy-in came into effect.

2430 - Enel, "Enel CEO met with the Slovak Minister of the Economy to Discuss Company's Future Plans", Press Release, 27 February 2007, see https://www.enel.com/media/explore/search-press-releases/press/2007/02/enel-ceo-met-with-the-slovak-minister-of-the-economy-to-discuss-companys-future-plans, accessed 20 August 2023.

2431 - IAEA, "Nuclear Power Reactors in the World", 2010 and 2011 editions. This date was later changed, and as of July 2023, Construction Restart Date is indicated as 27 January 2015. PRIS, "PRIS—Country Statistics—Mochovce-3", IAEA, 22 July 2023.

2432 - Martin Santa, "Enel wants more cash, more time for Mochovce plant -Slovak PM", *Reuters*, 19 December 2012, see https://www.reuters.com/article/slovakia-mochovce-idUSL5E8NJ8X020121219, accessed 21 August 2023.

2433 - Jan Lopatka, "Enel, Slovak government approve higher Mochovce nuclear plant budget", *Reuters*, 21 November 2014, see https://www.reuters.com/article/idUSKCN0J51UY20141121, accessed 21 August 2023.

2434 - Enel, "Sale of Enel Group Holdings in Slovakia and Romania Begins", Press Release, 10 July 2014, see https://www.enel.com/media/explore/search-press-releases/press/2014/07/sale-of-enel-group-holdings-in-slovakia-and-romania-begins, accessed 18 August 2023.

2435 - Jane Merriman, "CEZ bid for Enel's Slovak utility less likely amid government dispute", *Reuters*, 22 April 2015, see https://www.reuters.com/article/us-slovakia-cez-enel-idUSKBN0ND1WK20150422, accessed 21 August 2023.

2436 - Enel, "Enel signs agreement with EPH for sale of stake in Slovenské Elektrárne", Press Release, 18 December 2015, see https://www.enel.com/media/explore/search-press-releases/press/2015/12/enel-signs-agreement-with-eph-for-sale-of-stake-in-slovensk-elektrrne, accessed 4 August 2023.

2437 - Enel, "Enel signs Agreement on Enel Produziones Stake in Slovenské Elektrárne With Slovak Economy Ministry", Press Release, 21 December 2015.

By May 2016, the estimate for the total costs of completion of Units 3 and 4 had risen to €5.1 billion (US5.65_{2016}$ billion), with grid connection at the end of 2016 or early 2017.[2438] However, in March 2017, SE announced a considerable further delay in the project, with operation expected only at the end of 2018 and 2019 with an officially expected cost increase of only €300 million (US339_{2018}$ million).[2439]

In March 2019, Mochovce-3 completed "hot testing" in preparation for fuel loading in the summer. In June 2019, the period of decision regarding commissioning of Unit 3 was extended by six months due to "the large amount of inspection activities" to be performed; and authorization proceedings to commission Unit 4 were once more suspended by the Nuclear Regulatory Authority (ÚJD) which considered that SE "[had] not fully demonstrated that they have functional technological equipment."[2440] In September 2019, ÚJD concluded its evaluation of the hot hydrotests by announcing that it would require further modifications prior to fuel loading. According to *Nuclear Intelligence Weekly*, ÚJD Chair Marta Ziakova predicted commissioning of Unit 3 in the first half of 2020, and that of Unit 4 in 2021.[2441]

In January 2020, the nuclear regulator reported two major deficiencies at Unit 3 and SE had to submit a plan for corrective action.[2442]

Prior to the COVID-19 pandemic, fuel loading at Unit 3 had been expected at the beginning of the summer of 2020. In February 2020, Branislav Strýček, CEO of SE, indicated that "in the worst case" it would take place at "the end of 2020."[2443]

In April 2020, ÚJD received objections to its licensing decision from the Regional Government of Lower Austria and formal appeals from an Austrian environmental organization. In June 2020, the regulator announced another six month "extension of the period for decision in the administrative proceeding for authorization for commissioning of nuclear installation of the Unit 3", due to the impact of the pandemic on construction activities, and the assumption that large scope of inspections[2444] "caused by the identification of the substandard materials

2438 - *SITA*, "Ďalšie peniaze na Mochovce? Žiga nemá oficiálnu informáciu", as published in *Spravy Pravda* (in Slovak), 11 May 2016, see http://spravy.pravda.sk/ekonomika/clanok/392783-dalsie-peniaze-na-mochovce-ziga-nema-oficialnu-informaciu/, accessed 10 April 2021.

2439 - *WNN*, "Slovak utility increases Mochovce expansion budget", *World Nuclear News*, 31 March 2017, see http://www.world-nuclear-news.org/NN-Slovak-utility-increases-Mochovce-expansion-budget-31031701.html, accessed 10 April 2021.

2440 - ÚJD SR, "Decision No. 205/2019 To Suspend Administrative Proceedings", 4690/2019, Úradu jadrového dozoru Slovenskej republiky/Nuclear Regulatory Authority of Slovak Republic, see https://www.ujd.gov.sk/wp-content/uploads/2022/01/R205_2019_Unofficial_Translation.pdf; and ÚJD SR, "Nuclear Power Plant Mochovce VVER 4x440 MW Unit 3 – construction", 28 June 2019, see https://www.ujd.gov.sk/wp-content/uploads/2022/01/Prolongation-of-the-deadline-for-decision.pdf; both accessed 20 August 2023.

2441 - *NEI Magazine*, "Hot testing of Mohovce 3 revealed the need for further modifications", *Nuclear Engineering International*, 18 September 2019, see https://www.neimagazine.com/news/newshot-testing-of-mohovce-3-revealed-the-need-for-further-modifications-7413902/, accessed 10 April 2021; and *NIW*, "Briefs—Slovakia", *Nuclear Intelligence Weekly*, 31 January 2020.

2442 - *NIW*, "Briefs—Slovakia", *Nuclear Intelligence Weekly*, 31 January 2020.

2443 - SE, "Mochovce 3: Nuclear authority issued a draft decision on fuel loading", Press Release, Slovenske Elektrarne, 18 February 2020, see https://web.archive.org/web/20210318174901/https://www.seas.sk/article/mochovce-3-nuclear-authority-issued-a-draft-decision-on-fuel-loading/409, accessed 20 August 2023.

2444 - For more information on these inspections and the findings refer to ÚJD SR, "Opinion of ÚJD SR on the Identified Substitution of Material of Components Used in the Construction of Units 3&4 of Mochovce NPP", Úradu jadrového dozoru Slovenskej republiky/Nuclear Regulatory Authority of the Slovak Republic, May 2020, see https://www.ujd.gov.sk/wp-content/uploads/2022/01/Opinion-of-UJD-SR-on-the-Identified-Substitution-of-Material-of-Components-Used-in-the-Construction-of-Units-3.pdf, accessed 12 September 2023; and ÚJD SR, "Final results of quality inspections of the pipeline components", Úradu jadrového dozoru Slovenskej republiky/Nuclear Regulatory Authority of the Slovak Republic, 10 November 2021, see https://www.ujd.gov.sk/final-results-of-quality-inspections-of-the-pipeline-components/?lang=en, accessed 21 August 2023.

installed at the Unit 4" in 2019 and the likely subsequent replacement of metallurgical components would exceed the initial deadline.[2445]

In December 2020, an additional loan agreement was made between ENEL and SE for up to €570 million (US$$_{2020}$679.5 million), to enable the completion of both units. This brought the estimated completion cost to €6.2 billion (US$$_{2020}$7.4 billion), with fuel loading at Unit 3 then expected by April 2021—it did not happen—and at Unit 4 in 2023, which will not happen either.[2446]

By March 2021, fuel loading at Unit 3 was expected in the Autumn and in May 2021, ÚJD issued permits allowing operation as well as related permits for radioactive waste and used fuel management.[2447]

In January 2022—following a review of the appeals received in April 2021—ÚJD published its second instance draft decision to permit the commissioning of Mochovce-3, opening a new public consultation round until the beginning of March.[2448]

On 25 August 2022, ÚJD gave Unit 3 final clearance for commissioning.[2449] Mochovce-3 reached first criticality on 22 October 20222450 and was finally connected to the grid on 31 January 2023.[2451] As of July 2023, Unit 3 operates at 75 percent capacity, and generation at full capacity is expected in September–October 2023.[2452] Meanwhile Mochovce-4 is scheduled to come online sometime in 2024.[2453]

The grid connection of Unit 3, planned for 2012 at construction restart, happened with a ten-year delay. Unit 4 is delayed by at least eleven years, the connection date having been set to

2445 - ÚJD SR, "Announcement of the Nuclear Regulatory Authority of the Slovak Republic on the extension of the period for decision in the administrative proceeding for authorization for commissioning of nuclear installation of the Unit 3 - NPP Mochovce", Press Release, Úrad jadrového dozoru Slovenskej republiky/Nuclear Regulatory Authority of the Slovak Republic, 16 June 2020.

2446 - Enel, "Enel updates agreement with EPH for sale of stake in Slovenské elektrárne", Press Release, 22 December 2020, see https://www.enel.com/media/explore/search-press-releases/press/2020/12/enel-updates-agreement-with-eph-for-sale-of-stake-in-slovensk-elektrrne; and *WNN*, "Mochovce new-build project receives loan boost", *World Nuclear News*, 24 December 2020, see https://www.world-nuclear-news.org/Articles/Mochovce-new-build-project-receives-loan-boost, accessed 20 August 2023.

2447 - *NEI Magazine*, "Slovak regulator issues permit for commissioning of Mochovce 3", *Nuclear Engineering International*, 17 May 2021, see https://www.neimagazine.com/news/newsslovak-regulator-issues-permit-for-commissioning-of-mochovce-3-8749322, accessed 5 July 2021.

2448 - ÚJD SR, "Publication of the basis for the second instance decision on Mochovce Unit 3", Úradu jadrového dozoru Slovenskej republiky/Nuclear Regulatory Authority of Slovak Republic, Updated 25 January 2022, see https://www.ujd.gov.sk/publication-of-the-basis-for-the-second-instance-decision-on-mochovce-unit-3/?lang=en; and *WNN*, "Mochovce 3 to get commissioning licence", 26 January 2022, see https://www.world-nuclear-news.org/Articles/Mochovce-3-to-get-commissioning-licence; both accessed 7 August 2023.

2449 - ÚJD SR, "ÚJD SR issued the final authorization for commissioning of the Nuclear Power Plant Mochovce Unit 3", Úradu jadrového dozoru Slovenskej republiky/Nuclear Regulatory Authority of Slovak Republic, Updated 25 August 2022, see https://www.ujd.gov.sk/ujd-sr-issued-the-final-authorization-for-commissioning-of-the-nuclear-power-plant-mochovce-unit-3/?lang=en; and ÚJD SR, "Decision No. 248/2022P", No. 6356, File No. 738-2022, 25 August 2022, see https://www.ujd.gov.sk/wp-content/uploads/2022/09/decision-248-2022-P_English-version_final_anonymizovana-1.pdf; accessed 20 August 2023.

2450 - Kamen Kraev, "Mochovce-3 Generates First Power After Successful Grid Connection", *NucNet*, 1 February 2023, see https://www.nucnet.org/news/mochovce-3-generates-first-power-after-successful-grid-connection-2-3-2023, accessed 18 August 2023.

2451 - *NEI Magazine*, "Delays for Mochovce 3", 9 December 2022, see https://www.neimagazine.com/news/newsdelays-for-mochovce-3-10422185; and SE, "Mochovce 3 first connection to the grid", Press Release, Slovenské Elektrárne, 1 February 2023, see https://www.seas.sk/en/press-releases/mochovce-3-grid-connection/; both accessed 18 August 2023.

2452 - SE, "Mochovce NPP: Unit 3 already at 75% capacity", Press Release, Slovenské Elektrárne 17 July 2023, see https://www.seas.sk/en/press-releases/mochovce-npp-unit-3-already-at-75-capacity/, accessed 17 July 2023.
Output increased to 90 percent in August 2023, see SE, "Mochovce Unit 3 already at 90 % power", Press Release, 14 August 2023, see https://www.seas.sk/en/press-releases/mochovce-unit-3-already-at-90-power/?, accessed 20 August 2023.

2453 - *NEI Magazine*, "Mochovce 3 approved for energy start-up", *Nuclear Engineering International*, 20 January 2023, see https://www.neimagazine.com/news/newsmochovce-3-approved-for-energy-start-up-10531895, accessed 22 January 2023.

2013, and uncertainty remaining regarding the currently planned connection in 2024. At the time of project relaunch in 2007 (construction restarted in 2009), costs for the total project had been estimated at €$_{2007}$1.8 bn (€20202.2 bn); the most recent estimate from December 2020 puts total project costs at €20206.2 bn, close to a three-fold increase.

The Jaslovské Bohunice site has also been considered for years to host further newbuild projects. JESS (Jadrová energetická spoločnosť Slovenska/Nuclear Energy Company of Slovakia), was founded in 2009 by Slovak decommissioning-company JAVYS (51 percent) and Czech utility CEZ for the extension of the Bohunice site, the so-called Project NJZ. The Environmental Impact Assessment and the preferred project to establish a single Gen III+ PWR with a 1,700 MW capacity, received Governmental approval in 2016.[2454] In February 2023, JESS lodged a construction license request with the Slovak Nuclear Regulatory Authority for a new reactor at the Bohunice site, while SE executives point to the need for other, more flexible, electricity generation technologies.[2455] In July 2023, JAVYS signed a Memorandum of Understanding with Westinghouse for cooperation on the deployment of its AP-1000 and AP300 SMR in Slovakia.[2456] While no prospective sites have been named at this stage, it seems reasonable to assume that Bohunice will at least be considered during site exploration for the AP-1000.

In June 2023, SE and the Ministry of Economy applied for a US$2 million grant from the U.S. Government's "Project Phoenix" that aims at "accelerat[ing] the global clean energy transition by providing technical assistance to support decision-making on pursuing the conversion of one or more coal-fired power plants to secure and safe zero-carbon' SMR nuclear energy generation" for Eastern European and Eurasian countries.[2457] If the grant is approved, SE plans to conduct an SMR feasibility study.[2458]

Prompted by Russia's attack on Ukraine, the Slovak government agreed with SE on a supply-and-pricing agreement to curb high electricity prices for households. For 2023 and 2024, SE will supply 6.15 TWh respectively, at €61.20 per MWh (US$66.94/MWh). The agreement was extended in 2023 to annually supply 5.5 TWh to Slovak households for €66.70 per MWh (US$72.96/MWh) in 2025, €72.70 per MWh (US$78.97/MWh) in 2026 and €79.30 per MWh

2454 - Ministry of the Environment, "Novy jadrovy zdroj v lokalite jaslocské Bohunice—Záverečné Stanovisko", 1404/2016 – 3.4/hp, Government of the Slovak Republic, 15 April 2016 (in Slovak), see https://www.jess.sk/media/1471-2023_zs-njz-jaslovske-bohunice-zverejnene-15-04-2016-pdf.pdf; and JESS, "The Ministry of Environment of the Slovak Republic issued a positive final opinion on the project of a new nuclear source", Press Release, Jadrová energetická spoločnosť Slovenska, 15 April 2016, see https://www.jess.sk/en/the-ministry-of-environment-of-the-slovak-republic-issued-a-positive-final-opinion-on-the-project-of-a-new-nuclear-source; both accessed 22 August 2023.

2455 - Michal Hudec, "Slovakia may build new nuclear power plant as electricity consumption rises", *Euractiv*, 28 February 2023, see https://www.euractiv.com/section/politics/news/slovakia-may-build-new-nuclear-power-plant-as-electricity-consumption-rises/, accessed 7 June 2023.

2456 - Westinghouse, "Interest in Westinghouse AP300™ Small Modular Reactor, AP1000® Technology Surging in Europe as Slovakia Begins Deployment Discussions", Press Release, 17 July 2023, see https://info.westinghousenuclear.com/news/westinghouse-ap300-smr-ap1000-interest-in-europe-slovakia-deployment-discussions, accessed 22 August 2023.

2457 - *WNN*, "Slovakia submits bid for SMR feasibility study funding", *World Nuclear News*, 13 June 2023, see https://www.world-nuclear-news.org/Articles/Slovenske-elektrarne-pushes-ahead-on-SMR-plans, and FIRST, "Project Phoenix—Out of the Ashes – Conversion of Coal to Clean SMR Energy Supply", Undated, Foundational Infrastructure for Responsible Use of SMR Technology, U.S. Department of State, see https://www.smr-first-program.net/project-phoenix/; both accessed 22 August 2023.

2458 - Slovenské Elektrárne, "Slovenské elektrárne and its partners take the first step towards the construction of a small modular reactor", 12 June 2023, see https://www.seas.sk/en/press-releases/slovenske-elektrarne-and-its-partners-have-taken-the-first-step-towards-the-construction-of-a-small-modular-reactor/, accessed 22 August 2023.

(US$86.74/MWh) in 2027. The agreement is however still awaiting approval by the European Commission.[2459]

Like other countries in the region, the Slovak energy sector relies heavily on Russian supply. As of April 2023, reportedly, 60 percent of natural gas, 95 percent of oil and all nuclear fuel for the VVER-440 reactors came from Russia. Despite this dependency, Slovakia supports Ukraine with military equipment and financial aid. Attempts on supply diversification are hampered by Slovakia's only refinery only being able to effectively process Russia's Ural's grade crude oil, and limited suppliers of VVER fuel. For the latter, negotiations with other potential vendors are "going positively", according to State Secretary for Energy Peter Gerhardt.[2460] Two fuel deliveries in March 2022 to cover supply for 2022 and some of 2023, as Russian cargo planes were granted exemption from the ban of Russian aircraft in European airspace, showcase the level of current dependence.[2461]

In May 2023, Framatome and SE signed a Memorandum of Understanding to cooperate on the provision of "100% European" fuel for VVER reactors, while as of July 2023,[2462] Westinghouse remains the only Western producer of VVER fuel[2463].

Slovak power production is highly dependent on nuclear energy. In 2022, over 59 percent of electricity was produced by nuclear, followed by hydro at around 14 percent, and natural gas, bioenergy, and coal with single digit percentages. Solar PV made up just 2.6 percent of generation.[2464] Over the past decade, Slovak solar PV capacity has slowly but steadily increased to 573 MW by 2022. Despite a theoretical rooftop potential of around 37 GW, 2030 targets envision just 1.2 GW of installed PV capacity. The installed hydro capacity lies at around 2.6 GW and is not expected to increase in the coming years. Several studies have concluded Slovakia's high potential for onshore wind, but development thereof has reportedly been halted by a series of "legislative, regulatory, administrative, [and] technical [...] barriers". The installed capacity lies at just 3 MW, with a total of five turbines at two wind farms. Current policies set a target of 500 MW installed wind capacity by 2030. Bioenergy capacities are expected to double to around 400 MW by 2030.[2465]

2459 - *WNN*, "Mochovce 3 output increased to 55%", *World Nuclear News*, 31 March 2023, see https://www.world-nuclear-news.org/Articles/Mochovce-3-output-increased-to-55, accessed 22 August 2023.

2460 - Victor Jack, "You don't scare us: Slovakia shrugs off Kremlin energy retaliation for arming Ukraine", *Politico*, 3 April 2023, see https://www.politico.eu/article/slovakia-russia-energy-fossil-fuel-retaliation-war-ukraine-jets/, accessed 22 August 2023.

2461 - *The Slovak Spectator*, "More Russian nuclear fuel lands in Slovakia", 16 March 2022, see https://spectator.sme.sk/c/22862758/more-russian-nuclear-fuel-lands-in-slovakia.html, accessed 22 August 2023.

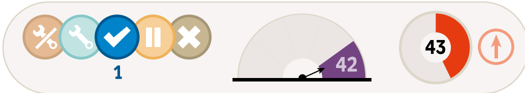
2462 - Framatome, "Framatome signs Memorandum of Understanding with Slovenské elektrárne to extend long-term partnership" Press Release, 31 May 2023, see https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-slovenske-elektrarne-to-extend-long-term-partnership/, accessed 23 July 2023.

2463 - Westinghouse, "Westinghouse's VVER-1000 Nuclear Fuel Fabrication Agreement Helps Cement Bulgaria's Energy Security", Press Release, 22 December 2022, see https://info.westinghousenuclear.com/news/westinghouse-vver-1000-nuclear-fuel-fabrication-agreement-helps-cement-bulgarias-energy, accessed 31 August 2023.

2464 - Statista, "Distribution of electricity generation in Slovakia in 2022, by source", based on data from Ember, June 2023, see https://www.statista.com/statistics/1236359/slovakia-distribution-of-electricity-production-by-source/, accessed 14 September 2023; and Ember, "Explore open data—Slovakia electricity generation by source", Updated April 2023, see https://ember-climate.org/countries-and-regions/regions/world/, accessed 6 November 2023.

2465 - Marian Maraffko, Boris Valach and Ján Karaba, "Slovak Renewable Electricity Market Report 2022", Slovak Association of Photovoltaic Industry and RES, February 2023, see https://www.sapi.sk/files/246_slovak-renewable-electricity-market-report-2022-finalpdf.pdf, accessed 14 September 2023.

Slovenia



Slovenia jointly owns the Krško nuclear power plant with Croatia—a 688-MW Westinghouse PWR. In 2022, it provided 5.3 TWh or 42.8 percent of Slovenia's electricity marking the highest nuclear share in the plant's operating history, although production was slightly down compared to 5.42 TWh generated in 2021. The operator notes in its Annual Report that production was lower than expected due to "exceptionally unfavourable environmental conditions (low Sava River water level and high temperature) and a longer outage period."[2466]

The reactor was first connected to the grid in 1981 and entered commercial operation in 1983, with an initial operational lifetime expectancy of 40 years. Thus, the plant's license was to expire this year, but in 2012, the regulator approved of the operator's refurbishment program,[2467] and in July 2015, an Inter-State Commission agreed in-principle to extend the plant's operating license to 60 years, so that it could continue providing power until 2043. In May 2016, a spokeswoman for the operator NEK (Nuklearna Elektrarna Krško), part of the GEN Group, clarified: "The lifespan of Krško has been extended providing that the plant passes a security [safety] check every 10 years with the next checks due in 2023 and 2033."[2468] In 2022, during the annual outage, further upgrading work was carried out including the replacement of the pressure turbine, while management had to cope with COVID-19 effects.[2469]

The lifetime extension project was met with fierce opposition from Parliament, civil society, and environmental organizations in neighboring Austria. In 2022, a report commissioned by the Austrian Government questioned various aspects of the Environmental Impact Assessment report presented by Slovenia, including the absence of reported progress on a final repository for nuclear waste, unsubstantiated safety levels, the resistance of systems and structures in case of seismic events, and shortcomings in terms of nuclear security[2470] (see previous WNISR editions).

Nevertheless, after having received the application in October 2021 and having carried out extensive consultation proceedings, in January 2023, the Slovenian Ministry of the Environment granted "environmental consent" approving the continued operation of Krško

2466 - Krško Nuclear Power Plant, "Annual Report 2022", 2023, see https://www.nek.si/upload/publications/ang-net.pdf, accessed 1 September 2023.

2467 - SNSA, "Slovenian Technical Review Report on the Krško NPP Ageing Management Program—Final Report", Slovenian Nuclear Safety Administration, Ministry of the Environment and Spatil Planning, Government of the Republic of Slovenia, December 2017, see https://www.ensreg.eu/sites/default/files/attachments/slovenia.pdf, accessed 2 September 2023.

2468 - *NEI Magazine*, "Life extension for Slovenia's Krs[k]o NPP", *Nuclear Engineering International*, 6 May 2016, see http://www.neimagazine.com/news/newslife-extension-for-slovenias-krslo-npp-4885976/; and SNSA, "Slovenian Technical Review Report on the Krško NPP Ageing Management Program—Final Report", Slovenian Nuclear Safety Administration, Ministry of the Environment and Spatil Planning, Government of the Republic of Slovenia, December 2017, see https://www.ensreg.eu/sites/default/files/attachments/slovenia.pdf; both accessed 2 September 2023.

2469 - NEK, "Krško Nuclear Power Plant back online after outage", Nuklearna elektrarna Krško/Krško Nuclear Power Plant, 8 November 2022, see https://www.nek.si/en/news/news/krsko-nuclear-power-plant-back-online-after-outage; and NEK, "Krško Nuclear Power Plant Annual Report 2022", June 2023, see https://www.nek.si/upload/publications/ang-net.pdf; both accessed 2 September 2023.

2470 - Umweltbundesamt, BIEGE Nuklearexpertise, Ebner ZT and pulswerk, "Umweltverträglichkeitsprüfung—KKW Krško/ Slowenien—Laufzeitverlängerung', Federal Environment Agency, commissioned/published by the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation, and Technology, Government of Austria, 2022, see https://www.umweltbundesamt.at/uvp-kkw-krsko-lte, accessed 30 July 2022.

for an additional 20 years, allowing the plant to operate until 2043.[2471] In October 2021, the IAEA lead a Pre-SALTO (Safety Aspects of Long Term Operation) at the site, and a SALTO mission is scheduled to take place in May 2025.[2472]

The spent fuel dry storage facility also received its operating permit from the nuclear safety administration in October 2022, and was commissioned in early April 2023, when Holtec started loading spent fuel casks to the facility,[2473] thus completing all "physical improvements" of NEK's long-term Safety Upgrade Program which were required under Slovenia's Post-Fukushima stress test Action Plan as reviewed by European Regulators.[2474] All further measures of the national action plan were implemented by the end of 2021, and the first transfer of fuel from the reactor's pool to the storage facility was completed in August 2023.[2475]

In January 2010, an application was made by the nuclear operator to the Ministry of Economy to build an additional unit called JEK-2 at the Krško site. During the following decade, not much progress had been reported.

Slovenia's "Long-Term Strategy Until 2050" filed with the United Nations in 2021 assumes a 43 percent share of renewables in electricity production by 2030, and "a comprehensive examination of options for the long-term use of nuclear energy and the adoption of a decision relating to the construction of a new nuclear power plant by 2027" with small modular reactors among the considered options.[2476] This paved the way for the Ministry of Infrastructure to issue an "energy permit" to JEK-2 in July 2021, allowing further administrative proceedings to move forward.[2477]

In May 2022, GEN provided the following overview of the project status:[2478]

- Government issued the Energy Permit to GEN in July 2021,
- GEN prepared and submitted background documentation for spatial planning to Ministry for Infrastructure in December 2021,

2471 - Ministry of the Environment and Spatial Planning, "Life span of the Krško Nuclear Power Plant (NEK) extended until 2043", Press Release, Government of Slovenia, 16 January 2023, see https://www.gov.si/en/news/2023-01-16-life-span-of-the-krsko-nuclear-power-plant-nek-extended-until-2043/, accessed 3 March 2023.

2472 - IAEA, "IAEA Concludes Long Term Operational Safety Review of Slovenia's Krško Nuclear Power Plant", Press Release 63/2021, 15 October 2021, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-of-slovenias-krsko-nuclear-power-plant; and IAEA, "Peer Review and Advisory Services Calendar—Safety Aspects of Long Term Operation (SALTO), Undated, see https://www.iaea.org/services/review-missions/calendar?type=3169&year%5Bvalue%5D%5Byear%5D=&location=All&status=All; both accessed 2 September 2023.

2473 - Holtec, "Holtec Moves Krško's Used Fuel Into Slovenia's First Dry Storage Facility to Support Continued Plant Operations", Press Release, 5 April 2023, see https://holtecinternational.com/2023/04/05/holtec-moves-krskos-used-fuel-into-slovenias-first-dry-storage-facility-to-support-continued-plant-operations/, accessed 2 September 2023.

2474 - ENSREG, "Slovenia", Updated December 2021, see https://www.ensreg.eu/country-profile/Slovenia; and SNSA, "Updated of the Slovenian Post-Fukushima Action Plan", Slovenian Nuclear Safety Administration, Ministry of the Environment and Spatial Planning, Government of the Republic of Slovenia, December 2021, see https://www.ensreg.eu/sites/default/files/attachments/stress_test_nacp_slovenia_2021.pdf; both accessed 2 September 2021.

2475 - *WNN*, "First loading campaign complete at Krško dry storage facility", *World Nuclear News*, 23 August 2023, see https://world-nuclear-news.org/Articles/First-loading-campaign-complete-at-Krsko-dry-stora, accessed 2 September 2023.

2476 - Government of the Republic of Slovenia, "Resolution on Slovenia's Long-Term Climate Strategy Until 2050 (ReDPS50)", 24 August 2021, see https://unfccc.int/sites/default/files/resource/LTS1_SLOVENIA_EN.pdf, accessed 2 September 2023.

2477 - Ministry of Infrastructure, "Ministry of infrastructure issues an energy permit for the second nuclear reactor unit in Krško", Press Release, Government of the Republic of Slovenia, 20 July 2021, see https://www.gov.si/en/news/2021-07-20-ministry-of-infrastructure-issues-an-energy-permit-for-the-second-nuclear-reactor-unit-in-krsko/, accessed 2 September 2023.

2478 - Bruno Glaser and Tomaž Žagar, "GEN's vision for decarbonisation and energy independence - by 2035", GEN Energija, May 2022.

- Ministry for Infrastructure submitted formal proposal for Spatial Planning Process to Ministry for Environment on 30 March 2022,
- GEN is prepared for further steps that will follow in the official procedure for spatial planning process,
- The initiator and responsible for this process is the Ministry for Environment.

The assumption was that JEK-2 would reach full power around 2034. However, no supplier or specific reactor design has been chosen, other than it would be a pressurized water reactor. "Possible suppliers" have been listed as CGN with the HPR1000, Korea Hydro Nuclear Power (KHNP) with the APR1000, Westinghouse with the AP-1000 and EDF with an EPR1200-termed version of the EPR.[2479] Considering that China has never built a nuclear plant in a western country, KHNP's only foreign project in UAE has been cumulating multiple delays under very different regulatory conditions, Westinghouse's only AP-1000 construction project in the U.S. only recently came online after significant delays and cost overruns (see United States Focus), and the EPR1200 does not exist yet and has not even been licensed anywhere in the world, the official JEK-2 schedule presented appears highly unrealistic. Meanwhile, reports suggest that the Chinese option has been rejected, and emphasis has now been put towards American, Korean, and French technology.[2480]

Responding to a question what the alternative approach would look like if the schedule could not be met, GEN representatives replied "there is no Plan B" pointing to power imports as the only option.[2481] Energy experts from the Association of Ecological Movements of Slovenia are pointing to the relatively high final energy consumption in Slovenia—7 percent above E.U. average per capita—leaving plenty of room for efficiency. The solar potential on buildings alone has been estimated at 27 TWh, more than twice the current Slovenian electricity consumption. Additional solar potential is seen in floating plants on hydro dams and in agrivoltaics, and for the Association's energy expert to conclude: "In Slovenia, we can produce all the necessary energy, not just electricity, entirely from renewable energy sources, if we reduce energy waste and use the available renewable energy sources. Free of fossil and nuclear energy."[2482]

However, in 2022, the Slovenian electricity mix was heavily dependent on nuclear power, generating 5.31 TWh or 44.1 percent, renewables with 3.42 TWh or 28.4 percent, of which hydro generated over 3 TWh and solar only 0.27 TWh (corresponding to just 2.2 percent of the total mix). While fossil fuels, mainly lignite, accounted for the remaining 27.4 percent.[2483] Wind energy remains practically non-existent in the mix: the installation of a 250-kW wind turbine

2479 - Ibidem.

2480 - Borut Tavčar, "Če želimo napredek, Krško ne more biti edina lokacija za jedrsko tehnologijo", *DELO*, 18 October 2022 (in Czech), see https://www.delo.si/dpc-energetika/porocimo-se-z-drzavo-dobaviteljico accessed 6 June 2023.

2481 - Exchange between Mycle Schneider and GEN representatives Bruno Glaser and Tomaž Žagar during a visit to the GEN-Offices at Krško, 18 May 2022, organized by the Friedrich Ebert Foundation, Zagreb.

2482 - Matjaž Valenčič, "The future of Slovenia: Renewable energy, without fossil and nuclear", Unpublished, May 2022.

2483 - Energy-Charts, "Public Net Electricity Generation in Slovenia in 2022", Fraunhofer Institute for Solar Energy Systems, Updated 13 November 2023, see https://energy-charts.info/charts/energy_pie/chart.htm?l=en&c=SI&interval=year&year=2022, accessed 15 November 2023.

in September 2023 increased the current number of operational wind turbines in Slovenia to a total of three.[2484]

The surprising April 2022 election win of the center-left Freedom Movement might have some impact on the future of the energy and nuclear policy in the country. Prime Minister Robert Golob and his Environment Minister, both former energy executives, see promise in nuclear technology, including SMRs, but have stated to consider it "imperative to hear the people's opinion" and promised to introduce legislation to boost the development of renewable energies,[2485] while the Croatian government is in favor of expanding nuclear capacities.[2486] Prime Minister Golob also stated that once a technology has been selected for the newbuild project, a referendum would be held to "seek the broadest possible national consensus for constructing this unit." This decision would be made by the end of 2027.[2487] Golob put the price tag of JEK-2 at €11 billion (US$12 billion) "should Slovenia decide to go ahead with the largest of several possible units under consideration", referring to the reported cost of the EPR at Olkiluoto-3 in Finland.[2488]

In the meantime, the current Slovenian Government is being accused by the opposition of "dragging its heels" in terms of advancing the JEK-2 project and to instead promote renewable energy technology development.[2489] In July 2023, Prime Minister Golob called before Parliament for legislation to fasten the planning and construction process, further noting that, while some neighboring countries had manifested interest, Slovenia would not be able to finance the plant independently without a fast-tracked implementation.[2490] In January 2023, JEK-2 promoter GEN pushed back the potential timeline for construction completion and test operation from 2033 to 2035,[2491] while six months later PM Golob reportedly put the "realistic completion date" at 2047.[2492] If the latter was the case, than there would be an urgent need to come up with a plan B—e.g. large efforts on sufficiency, efficiency and the rapid expansion of renewables—to advance.

2484 - *Balkan Green Energy News*, "LEITWIND LTW42 250 kW, the third wind turbine installed in the entire state of Slovenia", 26 September 2023, see https://balkangreenenergynews.com/leitwind-ltw42-250-kw-the-third-wind-turbine-installed-in-the-entire-state-of-slovenia/, accessed 15 November 2023.

2485 - Igor Todorović, "Priority of new Government of Slovenia is to tackle energy crisis", *Balkan Green Energy News*, 6 June 2022, see https://balkangreenenergynews.com/priority-of-new-government-of-slovenia-is-to-tackle-energy-crisis/, accessed 8 July 2022.

2486 - *Al Jazeera*, "Plenković sa Janšom: Hrvatska podržava proširenje nuklearke Krško", 28 March 2022, see https://balkans.aljazeera.net/news/economy/2022/3/28/plenkovic-sa-jansom-hrvatska-podrzava-prosirenje-nuklearke-krsko, accessed 2 September 2023.

2487 - *WNN*, "Slovenian PM says referendum will be needed to approve new nuclear", *World Nuclear News*, 2 November 2022, see https://world-nuclear-news.org/Articles/Slovenian-PM-says-referendum-needed-for-new-nuclea; and John Adkins, "Cost Estimate For New Krško Plant Is €11 Billion, Prime Minister Says", *NucNet*, 4 July 2023, see https://www.nucnet.org/news/cost-estimate-for-new-krsko-plant-is-eur11-billion-prime-minister-says-7-2-2023; both accessed 2 September 2023.

2488 - John Adkins, "Cost Estimate For New Krško Plant Is €11 Billion, Prime Minister Says", *NucNet*, 4 July 2023, see https://www.nucnet.org/news/cost-estimate-for-new-krsko-plant-is-eur11-billion-prime-minister-says-7-2-2023, accessed 2 September 2023.

2489 - Sebastijan R. Maček, "Slovenian energy minister causes furore over new nuclear unit timeline", *Euractiv*, 16 March 2023, see https://www.euractiv.com/section/politics/news/slovenian-energy-minister-causes-furore-over-new-nuclear-unit-timeline/, accessed 2 September 2023.

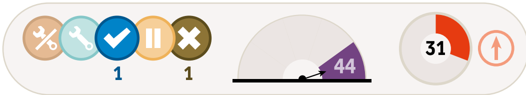
2490 - John Adkins, "Cost Estimate For New Krško Plant Is €11 Billion, Prime Minister Says", *NucNet*, 4 July 2023, op. cit.

2491 - Mihajlo Vujasin, "Second unit of Krško nuclear power plant projected to come online in 2035", *Balkan Green Energy News*, 27 January 2023, see https://balkangreenenergynews.com/second-unit-of-krsko-nuclear-power-plant-projected-to-come-online-in-2035/, accessed 2 September 2023.

2492 - John Adkins, "Cost Estimate For New Krško Plant Is €11 Billion, Prime Minister Says", *NucNet*, 4 July 2023, op. cit.

FORMER SOVIET UNION

Armenia



Armenia has one remaining reactor at the Metsamor (or Medzamor) nuclear power plant, also referred to as Armenian Nuclear Power Plant (ANPP), situated within 30 kilometers of the capital, Yerevan; it increased production in 2022 to 2.6 TWh, up from 1.8 TWh the previous year, and provided 31 percent of the country's electricity. This significant year-on-year production increase (44 percent) is due to upgrading works for which the unit underwent an outage of over 140 days in 2021—resulting in a particularly low yearly output that year—in turn allowing for a significant increase in 2022 to a record level. During the 2021-outage, the unit has been uprated from 407.5 MW to 448 MW (gross).[2493]

The reactor started generating in January 1980 and is a first-generation, Soviet-designed reactor, a VVER-440 v270. In December 1988, Armenia suffered a significant earthquake that led to the rapid closure of its two reactors in March 1989. During the early 1990s and following the collapse of the former Soviet Union, a territorial dispute between Armenia and Azerbaijan lead to an energy blockade that resulted in power shortages, leading to the Government's decision in 1993 to re-open Unit 2, which resumed operation in 1995.[2494]

Plans to build a new nuclear power plant were handed down by successive Governments for decades. As the project stalled over the years, Metsamor's closure—initially destined for early decommissioning—was gradually delayed further. Accordingly, in 2011, the Armenian Nuclear Regulatory Authority (ANRA) granted the reactor an extension of its operating license until 2021, subject to annual safety demonstrations starting in 2016, the initial expiration date.[2495] In October 2012, the Armenian Government announced that it planned to operate Metsamor until 2026. In 2015, Parliament approved a US$30 million grant and a loan of US$270 million from Russia towards upgrading works. However, following disagreements over the terms, Armenia decided in 2020 to turn down the remaining loan payments—about US$107 million according to *Reuters*—and the Government stepped-in with a loan of AMD63.2 billion ($\text{US\$}_{2020}$131 million).[2496] The engineering work enabling the reactor to operate until 2026 at an increased output was completed in November 2021.[2497]

The power plant has been a source of tension with neighboring countries for decades, most notably with Azerbaijan. The situation escalated in July 2020, when a senior Azerbaijani

2493 - IAEA, "Country Nuclear Power Profiles 2022 Edition—Armenia", International Atomic Energy Agency, Updated 2022, see https://cnpp.iaea.org/countryprofiles/Armenia/Armenia.htm, accessed 24 August 2023.

2494 - WNA, "Nuclear Power in Armenia", World Nuclear Association, Updated May 2023, see https://world-nuclear.org/information-library/country-profiles/countries-a-f/armenia.aspx, accessed 24 August 2023.

2495 - IAEA, "IAEA Concludes Long-Term Operational Safety Review at Armenia's Nuclear Power Plant", Press Release 61/2018, 10 December 2018, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-armenias-nuclear-power-plant, accessed 23 August 2023.

2496 - David Dalton, "Country Has Failed To Agree Loan With Russia, Says Prime Minister", *NucNet*, 15 June 2020, see https://www.nucnet.org/news/country-has-failed-to-agree-loan-with-russia-says-prime-minister-6-1-2020; and Nvard Hovhannisyan, "Armenia, Russia fail to agree on loan for nuclear plant upgrade", *Reuters*, 11 June 2020, see https://www.reuters.com/article/armenia-russia-nuclear-idAFL8N2DO37T; both accessed 24 August 2023.

2497 - *NEI Magazine*, "Life extension work completed at Armenian NPP", *Nuclear Engineering International*, 18 November 2021, see https://www.neimagazine.com/news/newslife-extension-work-completed-at-armenian-npp-9260626/, accessed 16 July 2023.

official threatened a missile strike against Metsamor during renewed fighting on the Armenia-Azerbaijan border. Around the same time, Galib Israfilov, Azerbaijan's ambassador to the IAEA—who condemned the threats against the plant—sent a letter to the Director General in which he said the "continued operations of Metsamor NPP would be a high risk for the entire region due to potential earthquakes in the immediate area."[2498] In the past, Turkish Governments and officials have also expressed their concerns over safety at the ageing facility to the IAEA and called for its closure.[2499]

The European Nuclear Safety Regulators Group (ENSREG) issued E.U. Peer Review Reports of the Armenian Stress Test in June 2016,[2500] and on the Implementation of the Armenian Stress Test National Action Plan in November 2019,[2501] confirming numerous safety-related problems.

Decommissioning has been encouraged beyond bordering countries. The E.U. has insisted on the decommissioning of Metsamor for decades, even making it official policy, or as summarized by the International Energy Agency in 2022: "An agreement in principle to close the ANPP, along with offers of assistance to do so, have been part of almost every major agreement between the E.U. and Armenia since at least 1998", yet the reactor was kept in operation.[2502] The Comprehensive and Enhanced Partnership Agreement (CEPA) contracted with the European Union in 2017 included cooperation on "the closure and safe decommissioning of Medzamor nuclear power plant and the early adoption of a road map or action plan to that effect taking into consideration the need for its replacement with new capacity to ensure the energy security of the Republic of Armenia and conditions for sustainable development."[2503] But in February 2020, Armenian Government officials said that they were considering, as part of the country's 2040 energy strategy, further extending the lifetime of the reactor.[2504] In December 2020, the European Commission reiterated "The nuclear power plant located in Medzamor cannot be upgraded to fully meet internationally accepted nuclear safety standards, and therefore requires an early closure and safe decommissioning."[2505] Yet, Armenia's Strategic Program to 2040, issued in January 2021—right before the CEPA entered into force—did not

2498 - Phil Chaffee, "Interview: Azerbaijan Eager for Mechanism to Address Metsamor Concerns", *Nuclear Intelligence Weekly*, 7 August 2020.

2499 - *Daily Sabah*, "Turkey pushes for closure of Armenian reactor", 24 March 2014, see https://www.dailysabah.com/politics/2014/03/24/turkey-pushes-for-closure-of-armenian-reactor ; and *Anadolu Agency*, "Armenian nuclear plant should be shut down: Turkey", 26 September 2016, see https://www.aa.com.tr/en/economy/armenian-nuclear-plant-should-be-shut-down-turkey/653168; both accessed 24 August 2023.

2500 - ENSREG, "EU Peer Review Report of the Armenia Stress Tests", European Nuclear Safety Regulators Group, June 2016, see http://www.ensreg.eu/document/armenia-stress-tests-peer-review-20-24-june-2016, accessed 16 July 2023.

2501 - ENSREG, "EU Peer Review Report Implementation of Armenian Stress Test national Action Plan", European Nuclear Safety Regulators Group, November 2019, see https://www.ensreg.eu/sites/default/files/attachments/armenia_nacp_peer_review_report-november_2019.pdf, accessed 23 August 2023.

2502 - IEA, "Armenia 2022—Energy Policy Review", 2022, International Energy Agency, see https://iea.blob.core.windows.net/assets/8328cc7c-e65e-4df1-a96f-514fdd0ac31e/Armenia2022EnergyPolicyReview.pdf, accessed 24 August 2023.

2503 - European Union, European Atomic Energy Community and the Republic of Armenia, "Comprehensive and Enhanced Partnership Agreement", Official Journal of the European Union, 26 January 2018, see https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22018A0126(01); and European Commission, "The EU and Armenia Comprehensive and Enhanced Partnership Agreement enters into force", Press Release, 28 February 2021, see https://ec.europa.eu/commission/presscorner/detail/en/ip_21_782; both accessed 24 August 2023.

2504 - *NEI Magazine*, "Armenia considers further life extension for Metsamor", *Nuclear Engineering International*, 2 March 2020, see https://www.neimagazine.com/news/newsarmenia-considers-further-life-extension-for-metsamor-7802500, accessed 16 July 2023.

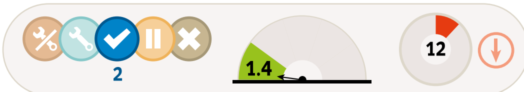
2505 - High Representative of the Union for Foreign Affairs and Security Policy, "Partnership Implementation Report on Armenia", Joint Staff Working Document SWD(2020) 366 final, European Commission, 16 December 2020, see https://data.consilium.europa.eu/doc/document/ST-14188-2020-INIT/en/pdf, accessed 24 August 2023.

only feature the construction of a new plant among its priorities, but also the extension of Metsamor beyond 2026.[2506]

In March 2023, the Armenian Government approved a strategy to operate the reactor until 2036 with an expected cost of US$150 million.[2507] In May 2023, a high-level meeting was held between the head of Rosatom and Armenia's Prime Minister to discuss the continual operation of Metsamor with the plan of work to start in 2024 and confirmation of plans to build an additional reactor.[2508]

Russia's invasion of Ukraine further tested its relationship with countries in the region, and despite their longstanding relationship, Armenia is seeking to expand its strategic relationships with third countries including a defense co-operation agreement with India. In May 2022, the U.S. and Armenian Governments signed an MoU on civil nuclear power, including co-operation on energy security and strengthening diplomatic and economic relationships.[2509] And in September 2022, then speaker of the U.S. House Nancy Pelosi visited Armenia.[2510]

Belarus



Construction started in November 2013 at Belarus's first nuclear reactor at the Ostrovets power plant, also called Belarusian-1. Construction of a second 1200 MWe AES-2006 reactor started at the same site in June 2014. The first unit was completed and connected to the grid on 3 November 2020 and reached full power in January 2021.[2511] In May 2023, the Belarussian Energy Ministry announced that the second unit was connected to the grid.[2512]

In 2022, Belarusian-1 provided 4.4 TWh, down from 5.4 TWh the previous year, representing a share of 11.9 percent, down from 14 percent in 2021, of the electricity production. The load factor in the first two years since grid connection was only 50 percent. The reasons are unclear.

The first few weeks of operation of Unit 1 reignited the international controversy around the project, and according to the Lithuanian Government, three incidents of equipment failure

2506 - Ministry of Territorial Administration and Infrastructure, "Republic of Armenia Energy Sector Development Strategic Program to 2040", Government of the Republic of Armenia, as published by Armenian Energy Agency, 2020, see https://energyagency.am/public/uploads/news/pdf/EnergyStrategy_angleren.pdf, accessed 26 August 2023.

2507 - *Interfax*, "Utilization period of Armenian NPP extended until 2036", 23 March 2023, see https://interfax.com/newsroom/top-stories/88975/, accessed 24 August 2023.

2508 - *WNN*, "Armenia and Russia discuss Armenian 2 operating extension, and new nuclear", *World Nuclear News*, 4 May 2023, see https://www.world-nuclear-news.org/Articles/Armenia-discusses-second-nuclear-power-plant, accessed 24 August 2023.

2509 - U.S. Department of State, "The United States of America and the Republic of Armenia Sign a Memorandum of Understanding Concerning Civil Nuclear Cooperation", Press Release, U.S. Government, 2 May 2022, see https://www.state.gov/the-united-states-of-america-and-the-republic-of-armenia-sign-a-memorandum-of-understanding-concerning-strategic-civil-nuclear-cooperation/, accessed 16 July 2023.

2510 - Anna Ohanyan, "Is Armenia's Move to Join the ICC a Strategic Necessity or Geopolitical Suicide?", Carnegie Endowment for International Peace, 28 June 2023, see https://carnegieendowment.org/2023/06/28/is-armenia-s-move-to-join-icc-strategic-necessity-or-geopolitical-suicide-pub-90063, accessed 16 July 2023.

2511 - *NEI Magazine*, "Unit 1 of the Belarusian nuclear plant brought to 100% capacity", 14 January 2021, see https://www.neimagazine.com/news/newsunit-1-of-the-belarusian-nuclear-plant-brought-to-100-capacity-8453244/, accessed 16 July 2023.

2512 - *BelTA*, "Belarusian nuclear power plant's second unit now connected to country's power grid", *Belarusian Telegraph Agency*, 13 May 2023, see https://atom.belta.by/en/belaes_en/view/belarusian-nuclear-power-plants-second-unit-now-connected-to-countrys-power-grid-12216/, accessed 13 May 2023.

occurred in the first month (later confirmed by Belarus), including in the voltage transformer, the cooling system, and a steam noise absorber.[2513]

In February 2021, the European Parliament passed a resolution on Ostrovets, which

> encourages the Commission to work closely with the Belarusian authorities in order to suspend the starting process until all E.U. stress test recommendations are fully implemented, and all necessary safety improvements are in place

and

> invites the Commission to assess and propose measures to suspend electricity trade with Belarus in a manner that is compliant with the obligations under international trade, energy and nuclear law, in order to ensure that electricity produced in the Ostrovets plant does not enter the EU energy market while Estonia, Latvia and Lithuania are still connected to the BRELL network.[2514]

However, moving towards isolating Belarus is not a strategy universally adopted in the E.U., and in April 2023, Hungary signed an agreement with Belarus on nuclear co-operation. Hungary's Foreign Minister Peter Szijjarto was reported to have said, "Nuclear security is of universal, global interest, regardless of the geopolitical situation."[2515]

In May 2023, the Lithuanian Government sent a letter to the Belarussian Ministry of Emergency Situations requesting the suspension of the operation at Ostrovets. The letter suggested that there was a "lack of specific information of the nuclear power plant site selection and evaluation, NPP equipment resistance to seismic events and the effects of a large civil aircraft crash, implementation of stress tests recommendations, probabilistic safety assessment, fire hazard analysis and other safety issues."[2516]

Belarus has historically been an importer of electricity from Russia and Ukraine. However, the link to Ukraine was disconnected as soon as the Russian invasion of Ukraine started in February 2022.[2517] Lithuania is trying to get its neighbors to follow the ban on nuclear power from Belarus and uses the Espoo ruling to add weight to its claim.[2518] In February 2020, the Governments of Estonia, Latvia, and Lithuania declared they would oppose electricity purchases from the nuclear power plant, and in September 2020 their respective Energy Ministries reached a joint-agreement to that extent, pledging that "Energy trade with Belarus

2513 - Andrew Rettman, "Lithuania warns EU leaders on Belarus nuclear incidents", *EUobserver*, 11 December 2020, see https://euobserver.com/foreign/150358, accessed 16 July 2023.

2514 - European Paliament, "European Resolution of 11 February 2021 on the Safety of the Nuclear Power Plant in Ostrovets (Belarus)", 2021/2511(RSP), 11 February 2021, see https://www.europarl.europa.eu/doceo/document/TA-9-2021-0052_EN.html, accessed 1 May 2021.

2515 - *WNN*, "Hungary and Belarus agree nuclear energy cooperation", *World Nuclear News*, 13 April 2023, see https://www.world-nuclear-news.org/Articles/Hungary-and-Belarus-agree-nuclear-energy-cooperati, accessed 16 July 2023.

2516 - VATESI, "Belarusian NPP nuclear safety issues remain unresolved", Valstybinė atominės energetikos saugos inspekcija/ State Nuclear Power Safety Inspectorate of Lithuania, 29 May 2023, see http://www.vatesi.lt/index.php?id=551&L=1&tx_news_pi1%5Bnews%5D=1130&tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Baction%5D=detail&cHash=140ffaf72faefef8e8118bf5ee143160, accessed 29 May 2023.

2517 - Andrius Prochorenko and Anton Achremov, "Belarusian trends in 2022 Q4", Eastern Europe Studies Centre, 21 December 2022, see https://www.eesc.lt/en/publication/belarusian-trends-in-2022-q4/, accessed 16 July 2023.

2518 - After a lengthy proceeding initiated through a complaint filed by Lithuania in 2011, the Meeting Parties of the Espoo Convention ruled in February 2019 that in choosing the site for its nuclear power plant, Belarus failed to comply with the United Nations' Espoo convention on Environmental Impact Assessment in a Transboundary Context; see UNECE, "EIA/IC/S/4 Belarus", Undated, United Nations, see https://unece.org/environmental-policy/environmental-assessment/eiaics4-belarus, accessed 26 August 2023.

will cease after the launch of its nuclear power plant, and a system of certificates of origin of electricity will be implemented for this purpose" until synchronization of Baltic electricity systems expected for 2025.[2519] The sale of electricity to the West would make a significant difference for the project's economics due to higher prices. Furthermore, the inability to export the power will lead to significant overcapacity. Some have speculated that this is the reason for continuous delay of commissioning Unit 2.[2520] Consequently, President Alexander Lukashenko has said that the Government needed to devise ways to get the population to use more electricity.[2521]

In November 2020, following the first power production from Unit 1, Lithuanian transmission system operator Litgrid ceased all power trading with Belarus,[2522] but it was suggested that the disconnection was for 'repairs'.[2523] Trading did restart and was recorded by ENTSOE at the beginning of 2021.[2524] In response to the war in Ukraine, electricity import from Russia into E.U. member states has come under scrutiny, and in May 2022, the power exchange Nord Pool decided to stop trading Russian electricity from its only importer in the Baltic States, Russian utility Inter RAO.[2525] The Baltic grids synchronization with the rest of Europe will physically exclude the import of electricity from Belarus, regardless of where it comes from. While plans to implement the measure by the end of 2025 had been made before Russia's invasion of Ukraine[2526], Estonia, Latvia, and Lithuania have recently stated their intention to complete the process by February 2025[2527]. In the meantime, power continues to flow in both directions between Belarus and Lithuania.[2528]

The original agreement on the construction of the reactors was signed in October 2011 between the Belarus Nuclear Power Plant Construction Directorate and Russia's

2519 - Dominik Istrate, "Baltic States will not buy energy from Belarus NPP", *Emerging Europe*, 13 February 2020, see https://emerging-europe.com/news/baltic-states-will-not-buy-energy-from-belarus-npp/, accessed 16 July 2023; and Ministry of Economic Affairs and Communications, "Baltic States agree on electricity trade", Government of Estonia, 1 September 2020, see https://mkm.ee/en/news/baltic-states-agree-electricity-trade, accessed 25 August 2023.

2520 - Andrius Prochorenko and Anton Achremov, "Belarusian trends in 2022 Q4", Eastern Europe Studies Centre, 2022, op. cit.

2521 - President of Belarus, "Meeting to discuss measures to stimulate electricity consumption in households", Official Internet Portal of the President of the Republic of Belarus, 10 April 2020, see https://president.gov.by/en/events/meeting-to-discuss-measures-to-stimulate-electricity-consumption-in-households-23385, accessed 4 September 2023.

2522 - Andrius Sytas, "Lithuania stops Baltics power trade with Belarus, Russia over nuclear plant", *Reuters*, 3 November 2020, see https://www.reuters.com/article/litgrid-belarus-idUSKBN27J2CA, accessed 16 July 2023.

2523 - Ben Aris, "Ukraine and Lithuania imported record amounts of power from Belarus, but move to break ties with its power grid", *BNE Intellinews*, 17 February 2021, see https://www.intellinews.com/ukraine-and-lithuania-imported-record-amounts-of-power-from-belarus-but-move-to-break-ties-with-its-power-grid-203117/, accessed 4 September 2023.

2524 - ENTSO-E, "Power Statistics", European Network of Transmission System Operators for Electricity, 2023, see https://www.entsoe.eu/data/power-stats/, accessed 8 September 2023.

2525 - *CEE Energy News*, "Lithuania completely cuts imports of Russian energy supplies", 23 May 2022, see https://ceenergynews.com/ukraine-russia-crisis/lithuania-completely-cuts-imports-of-russian-energy-supplies/, accessed 16 July 2023.

2526 - Joanna Hyndle-Hussein and Kamil Klysinski, "The second unit of the Belarusian Nuclear Power Plant goes online", Ośrodek Studiów Wschodnich/Centre for Eastern Studies, 2 June 2023, see https://www.osw.waw.pl/en/publikacje/analyses/2023-06-02/second-unit-belarusian-nuclear-power-plant-goes-online, accessed 16 July 2023.

2527 - Directorate-General for Energy, "Estonia, Latvia & Lithuania agree to synchronise their electricity grids with the European grid by early 2025", European Commission, 3 August 2023, see https://energy.ec.europa.eu/news/estonia-latvia-lithuania-agree-synchronise-their-electricity-grids-european-grid-early-2025-2023-08-03_en, accessed 26 August 2023.

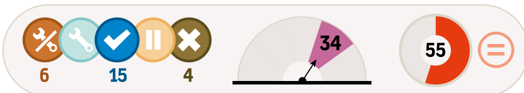
2528 - Energy-Charts, "Monthly cross border physical flows of Lithuania in 2023", Fraunhofer Institute for Solar Energy Systems, 11 September 2023, see https://energy-charts.info/charts/energy/chart.htm?l=en&c=LT&chartColumnSorting=default&source=cbpf_saldo&month=-1&legendItems=10000&sum=0&partsum=1, accessed 11 September 2023.

AtomStroyExport (ASE).[2529] The Russian and Belarusian governments agreed in November 2011 that Russia would lend up to US$10 billion for 25 years to finance 90 percent of the project. An amendment in 2021 extended the time from which the loan repayments would begin by two years, to start in April 2023, due to the later completion date.[2530] The project assumes Russian liability for all fuel supply and repatriation of spent fuel for the plant's life. The fuel will be reprocessed in Russia, and the separated wastes will be returned to Belarus. Information on the fate of the plutonium extracted during reprocessing is not available, but it is likely to remain in Russia.[2531]

While the complexity of nuclear plant constructions is often at the root of delays and cost overruns, at Ostrovets, the project also suffered from significant accidents, involving the reactor pressure vessels (RPV). In 2016 during its installation the RPV was dropped, which resulted in the replacement with a new one, which had been destined for another power plant in Russia (at the never completed Baltic station).[2532]

It is not easy to assess what the final investment will be. On the one hand, President Lukashenko has said in 2019 that cost would be below US$10 billion, but refused to reveal the actual number, stating: "It is a commercial secret. The contract price shouldn't be made public."[2533] However, given the scale of the delays and equipment changes keeping to the original budget would not have been possible.

Ukraine



Russia's unprovoked aggression and invasion of Ukraine in February 2022 continue to cause destruction and death on a level not seen in continental Europe for over 50 years. As the war now exceeds 500 days, there seems to be little indication that the conflict will end shortly. While the war is not about energy, it has unprecedentedly impacted global energy prices, resource availability, and energy policy. Furthermore, the continual attacks on and around the Zaporizhzhia nuclear power plant threaten the environment and safety across the continent (see Nuclear Power and War in WNISR2022).

Ukraine has 15 operating reactors, two of the VVER-440 design and the rest are VVER-1000s. Nuclear power provided 81 TWh or 55 percent of power generation in the country in 2021, with the figures for 2022 not available from the IAEA. However, according to the Statistical Review of World Energy, in 2022, nuclear net production was 59 TWh (62 TWh gross), a drop of

2529 - *Belta*, "Belarus, Russia sign contractual agreement to build NPP in Belarus", as published on Belarus.by, 11 October 2011, see https://www.belarus.by/en/press-center/news/belarus-russia-sign-contractual-agreement-to-build-npp-in-belarus_i_2751.html; and *WNN*, "Contract signed for Belarusian reactors", *World Nuclear News*, 11 October 2011, see https://www.world-nuclear-news.org/Articles/Contract-signed-for-Belarusian-reactors; both accessed 25 August 2023.

2530 - *TASS*, "Russia to grant up to $10 bln loan to Belarus for NPP project – Putin", *Russian News Agency*, 25 November 2011, see https://tass.com/archive/665290; and *NEI Magazine*, "Russia amends terms for Belarus NPP loan agreement", 29 March 2021, see https://www.neimagazine.com/news/newsrussia-amends-terms-for-belarus-npp-loan-agreement-8633297/; both accessed 25 August 2023.

2531 - *Interfax*, "Russia, Belarus sign agreement on management of spent nuclear fuel", 21 November 2022, see https://interfax.com/newsroom/top-stories/85185/, accessed 25 August 2023.

2532 - *WNN*, "Russia to use Baltic NPP reactor vessel for Ostrovets 2", *World Nuclear News*, 25 April 2017, see https://www.world-nuclear-news.org/NN-Russia-to-use-Baltic-NPP-reactor-vessel-for-Ostrovets-25041701.html, accessed 4 September 2023.

2533 - *BelTA*, "Belarusian nuclear power plant to cost less than $10bn", 19 April 2019, see https://eng.belta.by/president/view/belarusian-nuclear-power-plant-to-cost-less-than-10bn-120494-2019/, accessed 16 July 2023.

28 percent compared to 2021, with a nuclear share remaining at 55 percent of gross electricity generation.[2534] Such a reduction in nuclear production may be partly because the control of the Zaporizhzhia power plant in the East, which houses six VVER-1000 reactors, has been under the control of the Russian military and has hardly generated any power. Rosatom employees assist the military to direct Ukrainian staff forced to work at the plant under occupation.[2535]

Ukraine has carried out a safety upgrade program for all its reactors at an estimated cost of €1.45 billion (US$1.62 billion) in total, of which the European Bank for Reconstruction and Development (EBRD) and EURATOM contributed €600 million (US$670 million) between them. The program was first launched in 2011 with expected completion by 2017,[2536] but the disbursement of the loan has been gradual, delaying the conclusion of the upgrading to 2020.[2537]

The country has four closed reactors at the Chernobyl nuclear power plant including Unit 4 that underwent a disastrous accident in 1986. Three nuclear reactors (two VVER-440s and one VVER-1000) at Rovno (also spelled Rivne) have been granted a lifetime extension of 20 years,[2538] and three units at South Ukraine, one at Khmelnitski (or Khmelnytskyi, also Khmelnytski) and five units at Zaporizhzhia for ten years respectively. Following its 10-year extension, the current license of Unit 1 at South Ukraine is set to expire in December 2023, that of a further seven units will expire before 2030, and all others before 2040.[2539]

Two reactors, Khmelnitski-3 and -4, are officially under construction, but WNISR removed them from the construction list as no active work has been reported in over three decades, despite several attempts to revive the project. However, the current Ukrainian Government appears determined to have them finished. In 2018, the Government approved a feasibility study announcing a 84-months construction schedule, allowing for commissioning of the first unit in 2025.[2540] Reportedly preparatory works resumed in August 2020, and in September 2020, a Presidential decree instructed the Cabinet to submit a bill on Ukraine's power sector, including a long-term program for the development of nuclear energy to 2035, and addressing the location, design, and construction of the two units. At the time suggestions were that the total cost of completing Khmelnitski-3 and -4 was estimated at

2534 - Energy Institute, "Statistical Review of World Energy Data", 2023, see https://www.energyinst.org/statistical-review/resources-and-data-downloads, accessed 16 August 2023.

2535 - As independent verification of reports from the plant is hardly possible, as in WNISR2022, we have decided to abstain from a descriptive write-up of the events.

2536 - EBRD, "Nuclear Power Plant Safety Upgrade Program", Undated, see https://www.ebrd.com/work-with-us/projects/psd/nuclear-power-plant-safety-upgrade-program.html; and *WNN*, "Ukraine aims to complete safety upgrade program in 2020", *World Nuclear News*, 7 August 2015, see https://www.world-nuclear-news.org/Articles/Ukraine-aims-to-complete-safety-upgrade-program-in; both accessed 29 August 2023.

2537 - WNA, "Nuclear Power in Ukraine", World Nuclear Association, Updated May 2023, see https://world-nuclear.org/information-library/country-profiles/countries-t-z/ukraine.aspx, accessed 29 August 2023.

2538 - *NEI Magazine*, "Life extension for Ukraine's Rovno 3", *Nuclear Engineering International*, 23 July 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-rovno-3-6258731/, accessed 21 July 2023.

2539 - IAEA, "Country Nuclear Power Profiles—Ukraine" Updated 2020, see https://cnpp.iaea.org/countryprofiles/Ukraine/Ukraine.htm; and *NEI Magazine*, "Zaporozhye 5 licensed to operate until 2030", 8 January 2021, see https://www.neimagazine.com/news/newszaporozhye-5-licensed-to-operate-until-2030-8443511/; accessed 29 August 2023.

2540 - *NEI Magazine*, "Ukraine approves a feasibility study for Khmelnitsky 3&4", 31 July 2018, see https://www.neimagazine.com/news/newsukraine-approves-a-feasibility-study-for-khmelnitsky-34-6271521, accessed 29 August 2023.

UAH76.8 billion (US$$_{2020}$2.8 billion).[2541] In July 2021, Energoatom set a target of completing all pre-construction activities by 1 October 2021, adding, "Once the Law on KhNPP units 3 and 4 construction is adopted, everything will move very quickly."[2542]

However, given that these are Soviet/Russian-designed reactors it appears inconceivable that they will be completed to any semblance of their original design. Instead, following the outbreak of the war, there has been an increased interest in purchasing non-Russian reactors. Energoatom announced in June 2022 that it had increased the number of reactors it was interested in purchasing from Westinghouse from five to nine.[2543] Then, in January 2023, the Cabinet of Ministers approved the development of a feasibility study for constructing two AP-1000 reactors at Khmelnitsky to have them operational in 2032, noting that they would cost around US$5 billion each. Reportedly on that occasion, Ukraine's Energy Minister stated that "We hereby finally renounce Russian nuclear technologies in our nuclear power industry."[2544]

In May 2023, the Cabinet of Ministers approved a new Energy Strategy of Ukraine until 2050 which would include an objective that the share of renewable energy in its power generation would increase to 50 percent by 2035, while the other 50 percent of the power mix would be made up by nuclear power.[2545]

Ukraine has deployed efforts to move away from dependency on Russia for its nuclear fuel with Westinghouse providing fuel for some VVER 1000 reactors since 2005[2546] and reportedly, in March 2023 the head of Ukraine's regulatory authority stated that by the end of this year, Westinghouse would also be able to start delivering the fuel for the two VVER-440 reactors besides the fuel for the VVER-1000 design. In June 2022, Energoatom and Westinghouse signed a contract covering the fuel supply for all 15 Ukrainian reactors.[2547]

Also, in March 2023, Energoatom signed a contract with Cameco of Canada to supply all the uranium hexafluoride needs of Ukraine for the period 2024–2035. This will cover all the fuel

2541 - *NEI Magazine*, "Ukraine's president orders draft bill on development of nuclear energy", 24 September 2020, see https://www.neimagazine.com/news/newsukraines-president-orders-draft-bill-on-development-of-nuclear-energy-8148257; and *NEI Magazine*, "Working group reports on situation at Ukraine's Khmelnitsky nuclear plant", 6 October 2020, see https://www.neimagazine.com/news/newsworking-group-reports-on-situation-at-ukraines-khmelnitsky-nuclear-plant-8166180/; both accessed 21 July 2023.

2542 - Energoatom, "Energoatom intensifies works on Khmelnytskyi NPP unit 3 completion", Press Release, 23 July 2021, see http://www.energoatom.com.ua/en/press_center-19/company-20/p/energoatom_intensifies_works_on_khmelnytskyi_npp_unit_3_completion-47716, accessed 21 July 2023.

2543 - *WNN*, "Ukraine latest: Energoatom looks to future, SNRIU updates EU regulators", *World Nuclear News*, 20 June 2022, see https://www.world-nuclear-news.org/Articles/Ukraine-latest-Energoatom-looks-to-future,-SNRIU, accessed 21 July 2023.

2544 - *Ukrainian Energy*, "The government makes a decision to build two AP1000 power units at Khmelnytskyi NPP", 20 January 2023, see https://ua-energy.org/en/posts/20-01-2023-fcb4edf0-01a2-4c5a-8c1a-6b66691d742f, accessed 21 July 2023.

2545 - *Enerdata*, "Ukraine's government approves the Energy Strategy of Ukraine until 2050", 3 May 2023, see https://www.enerdata.net/publications/daily-energy-news/ukraines-government-approves-energy-strategy-ukraine-until-2050.html, accessed 21 July 2023.

2546 - *WNN*, "Westinghouse to enhance safety of Ukrainian VVER-440s", *World Nuclear News*, 14 June 2023, see https://world-nuclear-news.org/Articles/Westinghouse-to-enhance-safety-of-Ukrainian-VVER-4, accessed 4 September 2023.

2547 - *Ukrainian Energy*, "Ukraine Expects to Receive Westinghouse Nuclear Fuel for VVER-440 by the End of the Year", 9 March 2023, see https://ua-energy.org/en/posts/09-03-2023-7490e2b8-b75d-41d5-9676-d44c3dbc5087; and Westinghouse, "Energoatom and Westinghouse Reaffirm Clean Energy Partnership, Announce Expanded Cooperation on Westinghouse-supplied VVER Fuel and AP1000® Plants to be Built in Ukraine", Press Release, 3 June 2022, see https://info.westinghousenuclear.com/news/energoatom-and-westinghouse-reaffirm-clean-energy-partnership; both accessed 29 August 2023.

needs for Rovno, Khmelnitski and South Ukraine with the option for "up to 100% of the fuel requirements" for Zaporizhzhia once the facility is returned to Ukrainian control.[2548]

Before the Russian invasion, proposals were developed to introduce a direct power line from Khmelnitsky-2 to the European market. The Ukraine-E.U. Energy Bridge project, with an estimated cost of €243 million (US$$_{2019}$271 million), was to be carried out in the form of a public-private partnership between the Ukrainian state and an investor consortium consisting of Westinghouse Electric Sweden, Luxembourg-based Polish Polenergia International, and U.K.-based EDF Trading.[2549] However, on 24 February 2022, Ukraine decoupled its grid from Russia and operated in isolation until 16 March 2022 when it became synchronized to the E.U.'s grid.[2550]

Remarkably, in the Spring of 2023, Ukraine started exporting power to the E.U. and its neighbors, selling electricity in March to Hungary and Moldova, and then in April to Poland and Slovakia.[2551]

Russian Attacks on Nuclear Facilities

Russia invaded Ukraine from several directions, from North via Belarus, from the South, through Crimea and from the East through Donetsk and Luhansk. Russia immediately sought to take control of nuclear facilities, first the Chernobyl facility in the North on 24 February 2022 but troops were withdrawn on 31 March. Then the unprecedented attack on an operating civil nuclear power plant at Zaporizhzhia (ZNPP), Europe's largest by installed capacity, which took place on 4 March 2022 followed by a military takeover of the facility.

In October 2022, Vladimir Putin, in violation of international law, signed a decree that transfers ZNPP to Russian jurisdiction managed by Rosenergoatom, a Rosatom subsidiary. Rosenergoatom established a "Russian Federal State Unitary Enterprise ZNPP" to operate the plant.[2552] Despite this, is seems likely that a significant part of the workforce remains to be Ukrainians, as in January 2023 the IAEA reported that "only" one third of the workforce had left since the start of the conflict.[2553]

2548 - Cameco, "CCO and Energoatom Agree on Commercial Terms to Supply Ukraine's Full Natural UF6 Needs through 2035", Press Release, 8 February 2023 see https://www.cameco.com/media/news/cco-and-energoatom-agree-on-commercial-terms-to-supply-ukraines-full-natura, accessed 29 August 2023.

2549 - *Ukraine Energy*, "Winner of 'Ukraine-EU Energy Bridge' project is determined", 15 August 2019, see https://ua-energy.org/en/posts/15-08-2019-2370f1a2-3ba4-439b-b2d0-b8b382d349ab; and Ukrenergo, "'Ukrenergo' modernized the power transmission line between Ukraine and Poland", 2 May 2023, see https://ua.energy/general-news/ukrenergo-modernized-the-power-transmission-line-between-ukraine-and-poland/; accessed 30 August 2023.

2550 - Anna Blaustein, "How Ukraine Unplugged from Russia and Joined Europe's Power Grid with Unprecedented Speed", *Scientific American*, 23 March 2022, see https://www.scientificamerican.com/article/how-ukraine-unplugged-from-russia-and-joined-europes-power-grid-with-unprecedented-speed/, accessed 16 July 2022.

2551 - ENTSO-E, "Power Statistics", European Network of Transmission System Operators for Electricity, July 2023, see https://www.entsoe.eu/data/power-stats/, accessed 21 July 2023.

2552 - *The Kyiv Independent*, "Putin signs a decree to formalize Russia's illegal seizure of Zaporizhzhia Nuclear Power Plant", 5 October 2022, see https://kyivindependent.com/putin-signs-a-decree-to-formalize-russias-illegal-seizure-of-zaporizhzhia-nuclear-power-plant/; and Gareth Jones and David Ljunggren, "Putin asserts control over Ukraine nuclear plant, Kyiv disagrees", *Reuters*, 5 October 2022, see https://www.reuters.com/world/europe/zaporizhzhia-plant-operate-under-russian-supervision-after-annexation-ria-2022-10-05/; both accessed 4 September 2023.

2553 - IAEA, "Nuclear Safety, Security and Safeguards in Ukraine—February 2022–February 2023", International Atomic Energy Agency, February 2023, see https://www.iaea.org/sites/default/files/23/02/nuclear-safety-security-and-safeguards-in-ukraine-feb-2023.pdf, accessed 21 July 2023.

In early August 2022, ZNPP was under attack again affecting one reactor with additional damage to the spent fuel storage facility. In June 2023, the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) issued orders for all six reactors of the ZNPP to be put into cold shutdown. But Russia decided to keep one unit in hot shutdown (generating steam but no power), which serves "various nuclear safety purposes including the processing of radioactive waste collected in storage tanks", according to the IAEA.[2554]

In a February 2023 report, the IAEA documents 13 occasions in the first year of the conflict in which the power station was either shelled or mined and 16 occasions where it was fully or partially disconnected from the grid (external power is needed to cool the reactors and spent fuel even if the reactors are shut (see Nuclear Power and War in WNISR2022).[2555] The facility is also of strategic, economic and symbolic importance and it has been reported that Ukrainian attempts to retake control of the plant have been rebuffed.[2556]

It is not just direct attacks on the nuclear facilities that threaten their safety. The IAEA also notes that on 23 and 24 November 2022, the Rovno, South Ukraine, and Khmelnitsky nuclear power plants were automatically disconnected from the grid due to decreased grid frequency.[2557]

In early June 2023, an explosion at the Russian controlled Kakhovka dam, in Southern Ukraine, resulted in its breech and the flooding of vast amounts of land and numerous settlements, but the dam also retained the cooling water, the ultimate heat sink, for Zaporizhzhia.[2558] While there is no immediate danger, the available water will only be sufficient for several months. It is unclear what kind of solution can be engineered in the long run. The destruction of the dam was described as an Ecocide by the Ukrainian Environment Minister, Ruslan Strilets, referring to the destruction caused by the flooding and resulting pollution.[2559]

Furthermore, the war is affecting the ability of the plant management to undertake the necessary maintenance of the plants, due to lack of permanent staff, absence of external contractors and lack of spare parts, including critical components. The IAEA noted in April 2023 at the Zaporizhzhia plant currently there was only about one-quarter of its regular maintenance staff, which was affecting safety and security.[2560]

The Secretary General of the United Nations, António Guterres has expressed grave concern over the situation and has said, "Any damage - whether intentional or not - in Zaporizhzhia or

2554 - *WNN*, "Zaporizhzhia: Unit 4 in hot shutdown, IAEA reports mines", *World Nuclear News*, 25 July 2023, see https://world-nuclear-news.org/Articles/Zaporizhzhia-Unit-4-in%C2%A0hot-shutdown,%C2%A0IAEA-reports, accessed 26 July 2023.

2555 - IAEA, "Nuclear Safety, Security and Safeguards in Ukraine", International Atomic Energy Agency, February 2023, see https://www.iaea.org/sites/default/files/23/02/nuclear-safety-security-and-safeguards-in-ukraine-feb-2023.pdf, accessed 21 July 2023.

2556 - Maxime Tucker, "Ukraine's secret attempt to retake the Zaporizhzhia nuclear plant", *The Times*, 7 April 2023; and *NEI Magazine*, "The Times Confirms Russian Reports of Attacks on Zaporizhia NPP", April 2023, op. cit.

2557 - IAEA, "Nuclear Safety, Security and Safeguards in Ukraine", February 2023, op. cit.

2558 - François Diaz-Maurin, "Ukrainian dam is destroyed; nuclear plant lives in a 'grace period'", *Bulletin of the Atomic Scientists*, 6 June 2023, see https://thebulletin.org/2023/06/ukrainian-dam-is-destroyed-nuclear-plant-lives-in-a-grace-period/, accessed 8 June 2023.

2559 - Tim Schauenberg, "Ukraine: Destroyed Kakhovka dam amounts to 'ecocide'", *Deutsche Welle*, see https://www.dw.com/en/ukraine-destroyed-kakhovka-dam-amounts-to-ecocide/a-65849713, accessed 23 July 2023.

2560 - *WNN*, "Maintenance impacted at Zaporizhzhia, says IAEA", *World Nuclear News*, 24 April 2023, see https://www.world-nuclear-news.org/Articles/Maintenance-impacted-at-Zaporizhzhia,-says-IAEA, accessed 25 April 2023.

any other nuclear facility in Ukraine, could spell catastrophe".[2561] The European Commissioner Kadri Simson said in August 2022, "This reckless behavior [the shelling of the plant] by the Russian military forces poses a great danger to the plant's safe operation, increasing significantly the risk of a nuclear accident (...)"[2562]

Despite the international condemnation and the clear and immediate danger of the shelling and bombing of a nuclear facility as well as its power and water supplies, reportedly, attacks and threats of attacks continue.

2561 - *UN News*, "Ukraine: Guterres calls for safety and security of Zaporizhzhia nuclear plant", United Nations, 6 September 2022, see https://news.un.org/en/story/2022/09/1126131, accessed 21 July 2023.

2562 - Commissioner Kadri Simson, "Statement by Commissioner Simson on the situation at the Zaporizhzhia Nuclear Power Plant", Statement 22/8209, Commissioner for Energy, European Commission, 8 August 2022, see https://ec.europa.eu/commission/presscorner/detail/en/statement_22_8209, accessed 21 July 2023.

ANNEX 2 - STATUS OF NUCLEAR POWER IN THE WORLD

Table 28 · Status of Nuclear Power in the World (as of 1 July 2023)

Country	Nuclear Fleet					Power	Energy
	Operating		LTO	Mean Age[a]	Under Construction	Share of Commercial Electricity[b] (2022)	Share of Commercial Primary Energy[c] (2022)
	Units	Capacity (MW)	Units	Years	Units		
Argentina	3	1 641		32.8	1	5.4% (–)	1.9% (=)
Armenia	1	416		43.5		31% (+)	N/A
Bangladesh	-	-		-	2		
Belarus	2	2 220		1.4		11.9% (–)	3.7% (+)
Belgium	5	3 928		44.2		46.4% (–)	15.9% (=)
Brazil	2	1 884		32.1	1	2.5% (=)	1% (=)
Bulgaria	2	2 006		33.8		32.6% (–)	N/A
Canada	17	11 929	2	40/40.6		12.9% (–)	5.5% (=)
China	56	53 181	1	9.6	23	5% (=)	2.4% (=)
Czech Republic	6	3 934		32		36.7% (=)	16.8% (=)
Egypt					3		
Finland	5	4 394		35.7		35% (+)	19.5% (+)
France	55	60 040	1	38.1/38.2	1	63% (–)[d]	31.6% (–)
Germany						5.8% (–)	2.5% (–)
Hungary	4	1 916		38		47% (=)	14.6% (=)
India	19	6 290	3	25.2/21.4	8	3.1% (=)	1.2% (=)
Iran	1	915		11.8	1	1.7% (=)	0.5% (=)
Japan	10	9 486	23	32.4/35.2	1	6.1% (–)	2.6% (=)
Mexico	2	1 552		31.4		4.5% (=)	1.1% (=)
Netherlands	1	482		50		3.3% (=)	1.1% (=)
Pakistan	6	3 262		8.6		16.2% (+)	5.6% (+)
Romania	2	1 300		21.5		19.4% (=)	7.7% (=)
Russia	37	27 727		29.9	5	19.6% (=)	7% (=)
Slovakia	5	2 308		25.1	1	59.2% (+)	N/A
Slovenia	1	688		41.7		42.8% (+)	N/A
South Africa	2	1 854		38.6		4.9% (–)	1.9% (=)
South Korea	24	23 849	1	23.1/22.4	3	30.4% (+)	12.5% (+)
Spain	7	7 123		38.4		20.3% (=)	9.2% (=)
Sweden	6	6 937		41		29.4% (–)	20.2% (=)
Switzerland	4	2 973		47.3		36.4 (+)[e]	20% (+)
Taiwan	2	1 874		38.7		9.1% (–)	4.4% (=)
Turkey	-	-		-	4		
UAE	3	4 011		1.8	1	6.8% (+)	3.6% (+)
U.K.	9	5 883		36.1	2	14.2% (=)	5.9% (=)
Ukraine	15	13 107		34.4		55% (=)[c]	24% (=)
U.S.	93	95 835		42.1	1	18.2% (–)	7.6% (=)
EU27	99	95 054	1	37.2	2	21.6 (–)[c]	9.4% (–)
World	**407**	**364 943**	**31**	**31.5/31.4**	**58**	**9.2% (=)[c]**	**4% (=)**

Sources: WNISR with IAEA-PRIS, Energy Institute, 2023

(a) – Including reactors in LTO/Excluding reactors in LTO.

(b) – Data for 2022, from IAEA-PRIS, "Nuclear Share of Electricity Generation in 2022", as of July 2023, unless otherwise indicated.

(c) – Data for 2022, from Energy Institute, "Statistical Review of World Energy", 2023.

(d) – RTE, "Bilan Électrique 2022", Réseau de Transport d'Électricité/French Transmission System Operator, February 2023.

(e) – OFEN/SFOE, "Production et consommation totales d'énergie électrique en Suisse en 2022", Office Fédérale de l'Énergie/Swiss Federal Office of Energy, 2023.

ANNEX 3 – NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION"

Table 29 · Nuclear Reactors in the World "Under Construction" (as of 1 July 2023)

Country	Units	Capacity MW net	Model	Initial Construction Start	Expected Grid Connection	Delayed
Argentina	**1**	**25**				yes
Carem25		25	CAREM (PWR)	08/02/2014	2027[1]	yes
Bangladesh	**2**	**2 160**				
Rooppur-1		1 080	VVER V-523	30/11/2017	2024[2]	yes
Rooppur-2		1 080	VVER V-523	14/07/2018	2024[3]	likely
Brazil	**1**	**1 340**				
Angra-3[4]		1 340	PRE KONVOI	01/06/2010[5]	2028[6]	yes
China	**23**	**24 408**				
Changjiang SMR-1[7]		125	ACP100[8]	13/07/2021	2026[9]	
Changjiang-3		1 000	HPR-1000[10]	31/03/2021	2026[11]	
Changjiang-4		1 000	HPR-1000	28/12/2021	2026[12]	
Fangchenggang-4		1 000	HPR-1000	23/12/2016	2024[13]	yes
Haiyang-3		1 161	CAP1000	07/072022	2027[14]	
Haiyang-4		1 161	CAP1000	22/04/2023	2027[15]	
Lufeng-5		1 116	HPR-1000	08/09/2022	2027[16]	
Sanaocun-1		1 117	HPR-1000	31/12/2020	2026[17]	
Sanaocun-2		1 117	HPR-1000	30/12/2021	2027[18]	
Sanmen-3		1 163	CAP1000	28/06/2022	2027?[19]	
Sanmen-4		1 163	CAP1000	23/03/2023	2028?[20]	
Shidao-Bay 2-1[21]		1 400	CAP1400	04/2019[22]	2024[23]	
Shidao-Bay 2-2		1 400	CAP1400	11/2019[24]	2024[25]	
Taipingling-1[26]		1 116	HPR-1000	26/12/2019	2025[27]	
Taipingling-2		1 116	HPR-1000	15/10/2020	2026[28]	
Tianwan-7		1 171	VVER V-491	19/05/2021	2026[29]	
Tianwan-8		1 171	VVER V-491	15/02/2022	2027[30]	
Xiapu-1		642	CFR-600	29/12/2017	2023[31]	
Xiapu-2[32]		642	CFR-600	27/12/2020	2026?[33]	
Xudabu-3[34]		1 200	VVER V-491	19/05/2021	2027[35]	
Xudabu-4		1 200	VVER V-491	19/05/2022	2028[36]	
Zhangzhou-1		1 126	HPR-1000	16/10/2019	2024[37]	
Zhangzhou-2		1 126	HPR-1000	04/09/2020	2025[38]	

Country	Units	Capacity MW net	Model	Initial Construction Start	Expected Grid Connection	Delayed
Egypt	**3**	**3 300**				
El Dabaa-1		1 100	VVER 1200	20/07/2022	2028[39]	
El Dabaa-2		1 100	VVER 1200	19/11/2022	2029[40]	
El Dabaa-3		1 100	VVER 1200	03/05/2023	2030[41]	
France	**1**	**1 630**				
Flamanville-3		1 630	EPR	03/12/2007	2024[42]	yes
India	**8**	**6 028**				
Kakrapar-4		630	PHWR-700	22/11/2010	2024[43]	yes
Kudankulam-3		917	VVER V-412	29/06/2017	2025[44]	yes
Kudankulam-4		917	VVER V-412	23/10/2017	2025[45]	yes
Kudankulam-5		917	VVER V-412	29/06/2021	2026/2027[46]	likely[47]
Kudankulam-6		917	VVER V-412	20/12/2021	2027[48]	likely[49]
PFBR		470	FBR	23/10/2004	12/2024[50]	yes
Rajasthan-7		630	PHWR	18/07/2011	2026[51]	yes
Rajasthan-8		630	PHWR	30/09/2011	2026[52]	yes
Iran	**1**	**974**				
Bushehr-2		974	VVER V-446	02/1976[53]	2024[54]	yes
Japan	**1**	**1 325**				
Shimane-3		1 325	ABWR	12/10/2007	2025?[55]	yes
Russia	**5**	**2 810**				
BREST-OD-300		300	FBR	08/06/2021	2026[56]	
Kursk 2-1		1 200	VVER V-510	29/04/2018	2025[57]	yes
Kursk 2-2		1 200	VVER V-510	15/04/2019	2027[58]	yes
Cape Nagloynyn 1-1[59]		55	RITM-200S	30/08/2022	?	
Cape Nagloynyn 1-2		55	RITM-200S	30/08/2022	?	
Slovakia	**1**	**440**				
Mochovce-4		440	VVER V-213	01/01/1985	2024[60]	yes
South Korea	**3**	**4 020**				
Shin-Hanul-2		1 340	APR-1400	19/06/2013	2024[61]	yes
Saeul-3[62]		1 340	APR-1400	03/04/2017	10/2024[63] (commercial operation)	yes
Saeul-4		1 340	APR-1400	20/09/2018	10/2025[64] (commercial operation)	yes
Turkey	**4**	**4 456**				
Akkuyu-1		1 114	VVER V-509	03/04/2018	2024[65]	yes
Akkuyu-2		1 114	VVER V-509	08/04/2020	2025[66]	
Akkuyu-3		1 114	VVER V-509	10/03/2021	2026[67]	
Akkuyu-4		1 114	VVER V-509	21/07/2022	2027[68]	

Country	Units	Capacity MW net	Model	Initial Construction Start	Expected Grid Connection	Delayed
UAE	**1**	**1 310**				
Barakah-4		1 310	APR-1400	30/07/2015	2023[69]	yes
U.K.	**2**	**3 260**				
Hinkley Point C-1	1	1 630	EPR-1750	11/12/2018[70]	2027[71]	yes
Hinkley Point C-2	1	1 630	EPR-1750	12/12/2019[72]	2028[73]	yes
U.S.	**1**	**1 117**				
Vogtle-4		1 117	AP-1000	19/11/2013	2023[74]	yes
World	**58**	**58 603**		**1976–2023**	**2023–2030**	**24**

Notes:

1 - Delayed several times. The construction of CAREM, was suspended in 2019 "due to breaches by contractor companies". Concreting restarted in January 2022, with a startup expected in 2027.
See Matías Alonso, "Sol Pedre: 'El CAREM es un salto cualitativo para el sector nuclear argentino'", *Agencia TSS*, 2 June 2022 (in Spanish), see https://www.agenciatss.com.ar/sol-pedre-el-carem-es-un-salto-cualitativo-para-el-sector-nuclear-argentino/, accessed 8 November 2023; and ARN, "National Nuclear Safety Report—Argentinean National Report for the Convention on Nuclear Safety—Ninth Report", Autoridad Regulatoria Nuclear/Nuclear Regulatory Authority of Argentina, August 2022, see https://www.argentina.gob.ar/sites/default/files/national_nuclear_safety_report_2022.pdf, accessed 11 September 2022.

2 - First acknowledged delay. Startup at construction start was expected in 2023.
See Rosatom, "First concrete poured at the constructed Rooppur NPP site (Bangladesh)", Press Release, 30 November 2017, see http://www.rusatom-overseas.com/media/news/first-concrete-poured-at-the-site-constructed-npp-rooppur-bangladesh.html, accessed 17 August 2020.
Concerns about the implications of the financial sanctions on Russia arose as soon as March 2022, but were dismissed by Rosatom. See Masum Billah, "Western sanctions cast a cloud over Russia-backed Bangladesh nuclear power plant", *bdnews24.com*, 1 March 2022, see https://bdnews24.com/bangladesh/2022/03/02/western-sanctions-cast-a-cloud-over-russia-backed-bangladesh-nuclear-power-plant, accessed 5 April 2022.
In April 2023, Rosatom confirmed the delay, quoting Rooppur Project Director Muhammad Shawkat Akbar: "Hopefully, Unit 1 will be commissioned in September 2024".
See Rosatom, "Accelerating Towards Launch", Newsletter #264, April 2023, see https://rosatomnewsletter.com/2023/04/27/accelerating-towards-launch/, accessed 13 May 2023.
But startup might be further delayed. See Rejaul Karim Byron, "Rooppur Nuke Power Plant: Launching not before 2025", *The Daily Star*, 22 March 2023, see https://www.thedailystar.net/news/bangladesh/news/rooppur-nuke-power-plant-launching-not-2025-3277196, accessed 16 July 2023.

3 - Expected startup at construction start.
See Rosatom, "Main construction of the 2nd Unit of Rooppur NPP begins with the 'First Concrete' ceremony", Press Release, 14 July 2018, see http://rosatom.ru/en/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-npp-begins-with-the-first-concrete-ceremony/, accessed 15 July 2018.
Grid connection of Rooppur-2 is likely to be delayed, at least by a few months as well.
See previous note; and *The Daily Star*, "Rooppur power plant runs into further snag", 28 April 2023, see https://www.thedailystar.net/news/bangladesh/diplomacy/news/rooppur-power-plant-runs-further-snag-3305941, accessed 13 May 2023.

4 - Construction was halted in September 2015 in the wake of financial problems and a major corruption scandal. Restart of the project has been announced several times since but without specific information. Eventually, in November 2022, Eletrobras announced the "resumption of concrete pouring", marking the restart of the construction, and the reintroduction of Angra-3 in the WNISR list of constructions.
See Eletrobras, "Reinício da concretagem marca retomada das obras de Angra 3", Press Release (in Portuguese), 11 November 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Rein%C3%ADcio-da-concretagem-marca-retomada-das-obras-de-Angra-3.aspx, accessed 18 November 2022.
The outcome of a dispute regarding an embargo on the construction placed by the Angra dos Reis City Hall are still developing, and may delay the project further.
See "The Angra-3 Saga" in Brazil Focus for more details.

5 - The date of the actual construction start of Angra-3 is unclear. While site work was carried out as early as 1984, base slab concreting apparently did not take place until 2010.

6 - Delayed several times. 2028 is the expected startup date announced at construction restart in November 2022, but some delay is already expected, subject to construction restart.
See Eletrobras, "Reinício da concretagem marca retomada das obras de Angra 3", Press Release (in Portuguese), 11 November 2022, op. cit.

7 - The Changjiang SMR is listed as Linglong-1 (Hainan Changjiang SMR) in IAEA-PRIS statistics.

8 - The ACP100 also goes by the name Linglong One.

9 - CNNC, "Workshop on the Application of Small Modular Reactor held in Hainan", 8 September 2023, see https://en.cnnc.com.cn/2023-09/08/c_919054.htm, accessed 8 November 2023.

10 - The HPR-1000 also goes by the name Hualong One.

11 - Construction period is expected to be 60 months.
See *NEI Magazine*, "First concrete poured for China's Changjiang 3", 1 April 2021,
see https://www.neimagazine.com/news/newsfirst-concrete-poured-for-chinas-changjiang-3-8644649, accessed 2 April 2021.

12 - *WNN*, "Construction begins at second Changjiang Hualong One", *World Nuclear News*, 29 December 2021,
see https://world-nuclear-news.org/Articles/Construction-begins-at-second-Changjiang-Hualong-O, accessed 30 December 2021.

13 - Delayed. In January 2022, CGN adjusted the expected date of commencement of operation of Fangchenggang Unit 4 to the first half of 2024 (previously 2022).
See CGN Power, "Inside Information Construction Progress of Fangchenggang Units 3 and 4", 26 January 2022, see http://en.cgnp.com.cn/encgnp/c211222/2022-01/26/4197b03727be4723a8240db19375c3fc/files/cd02f04566144542ab87ed85fa32f35d.pdf, accessed 31 January 2022.

14 - No official startup date provided at construction start. WNISR used 2027, confirmed at construction start of Haiyang-4.
See following note.

15 - According to Shanghai Nuclear Engineering Research and Design Institute (SNERDI), construction time of Haiyang-3 and -4 is expected to be 56 months, with both units to be in operation in 2027.
See SNERDI, "海阳核电4号机组顺利实现FCD [Haiyang Nuclear Power Unit 4 Successfully Achieves FCD]", Press Release (in Chinese), Shanghai Nuclear Engineering Research & Design Institute Co, LTD., 22 April 2023,
see https://www.snerdi.com.cn/newsdetail?id=9277, accessed 28 April 2023.

16 - CGN Power, "Inside Information - Operation Briefings for the Fourth Quarter of 2022", 9 January 2023, see http://en.cgnp.com.cn/encgnp/c22122503/2023-01/09/5dea667175824ede9c0ff34882623bec/files/2537af48e9584a85bdd4130e23b7c749.pdf, accessed 8 November 2023.

17 - Commencement of operation of Sanaocun-1 (also known as San'ao or Cangnan-1) is expected in 2026.
See CGN Power, "Annual Report 2022", March 2023, see https://www1.hkexnews.hk/listedco/listconews/sehk/2023/0404/2023040401341.pdf, accessed 1 June 2023.

18 - Commencement of operation of Sanaocun-2 (also known as San'ao or Cangnan-2) is expected in 2027.
See CGN Power, "2022 Annual Report", March 2023, op. cit.

19 - No official information on expected startup date at construction start. World Nuclear Association (WNA) uses 2027.
See WNA, "Plans for New Nuclear Reactors Worldwide", Updated May 2023, see https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx, accessed 1 June 2023.

20 - No official information on expected startup date at construction start. World Nuclear Association (WNA) uses 2028.
See WNA, "Plans for New Nuclear Reactors Worldwide", Updated May 2023, op. cit.

21 - Provisional names for the two CAP1400 at Rongcheng/Shidaowan. Construction of those reactors was introduced in WNISR statistics in 2020 following *Nuclear Intelligence Weekly* (*NIW*) articles (in particular 10 July 2019) and confirmation from sources in China. In July 2019, *NIW* classified the two units as "under construction" on the basis of the Chinese National Nuclear Safety Administration (NNSA) map as of June 2019.
See *NIW Magazine*, "Chinese Power Reactor Project Wrapped in Secrecy", 12 July 2019.

22 - According to sources in China, first basemat concrete for the first CAP1400 reactor was poured on 8 April 2019.
See also C.F. Yu, "CGN's Taipingling Project Moves Ahead", *NIW Magazine*, 20 December 2019. See previous note.

23 - No official startup dates at this point. According to sources in China, the expected construction duration of CAP1400 from Zheng Mingguang is about 56 months. WNISR2023 uses 2024 as expected grid connection.

24 - According to sources in China, first basemat concrete for the second CAP1400 reactor was poured in November 2019. See previous notes.

25 - No official startup dates at this point. WNISR2023 uses 2024 for grid connection date. See previous notes.

26 - Also known as Huizhou.

27 - CGN, "Annual Report 2022", 2023, op. cit.

28 - Ibidem.

29 - According to sources in China, the contract between China and Russia stipulated a construction duration of 65 months. Rosatom stated about the Tianwan-7 and -8 project "the units are scheduled to be commissioned in 2026-2027".
See Rosatom, "Start of new unit construction at China's Tianwan and Xudapu nuclear power plants", Press Release, 19 May 2021,
see https://rosatom.ru/en/press-centre/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants, accessed 14 June 2021.

30 - See Rosatom State Corporation Engineering Division, "The First Concrete has been Laid at Tianwan NPP Power Unit 8 in China", Press Release, ASE Rosatom, 28 February 2022, see https://ase-ec.ru/en/for-journalists/news/2022/feb/the-first-concrete-has-been-laid-at-tianwan-npp-power-unit-8-in-china/, accessed 28 February 2022.

31 - *WNN*, "China begins building pilot fast reactor", *World Nuclear News*, 29 December 2017,
see http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html, accessed 30 December 2017.

32 - Unit introduced in IAEA-PRIS statistics in May 2023.

33 - No official information about expected grid connection. WNISR2023 uses 2026 (same duration as Xiapu-1).

34 - Also known as Xudapu or Xudabao.

35 - According to sources in China, the expected construction duration of VVER-1200/V491 is 69 months. At construction start, Rosatom stated about the Xudabao Project, "the units are expected to be commissioned in 2027-2028".

See Rosatom, “Start of new unit construction at China’s Tianwan and Xudapu nuclear power plants”, Press Release, 19 May 2021, https://rosatom.ru/en/press-centre/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants/, accessed 14 June 2021.

36 - According to Rosatom at construction start of Unit 4, commissioning of Xudabu-3 and -4 is scheduled for 2027–2028.
See ASE-Rosatom, “First Concrete laid at Xudapu NPP Power Unit 4 in China”, Press Release, 19 May 2022, see https://ase-ec.ru/en/for-journalists/news/2009/may/first-concrete-laid-at-xudapu-npp-power-unit-4-in-china/, accessed 19 May 2022.

37 - No official startup date at construction start.
See CNNC, “CNNC’s Zhangzhou nuclear plant goes into construction”, China National Nuclear Corporation, 23 December 2019, see http://en.cnnc.com.cn/2019-12/23/c_435889.htm, accessed 17 January 2020.
Construction duration of Hualong One design given as 60 months.

38 - No official startup date at construction start.
See *WNN*, “Zhangzhou unit 2 construction starts”, *World Nuclear News*, 4 September 2020, see https://www.world-nuclear-news.org/Articles/Construction-starts-of-second-Zhangzhou-unit, accessed 4 September 2020.
Construction duration of Hualong One design given as 60 months.

39 - *EgyptToday*, “Egypt’s Nuclear Plants Authority, Rosatom committed to Dabaa plant construction schedule: Official”, 9 May 2022, see https://www.egypttoday.com/Article/3/115597/Egypt’s-Nuclear-Plants-Authority-Rosatom-committed-to-Dabaa-plant-construction, accessed 17 July 2022.

40 - No official specific startup date for El Dabaa-2 as of construction date. As all four units are expected online by 2030 or 2031, WNISR2023 uses 2029 (WNA uses 2030 for both El Dabaa-2 and -3)

41 - No official specific startup date for El Dabaa-3 as of construction date. As all four units are expected online by 2030 or 2031, WNISR2023 uses 2030 (WNA uses 2030 for both El Dabaa-2 and -3).

42 - Further delayed. Delayed many times from its original planned startup date of 2012. In December 2022, EDF announced a new provisional date for fuel loading: by the first quarter of 2024 (compared to second quarter of 2023 in WNISR2022).
See EDF, “Update on the Flamanville EPR”, Press Release, 20 December 2022, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/update-on-the-flamanville-epr-0, accessed 1 January 2023.

43 - Delayed several times. In 2022, according to an internal memo from the Ministry of Energy, seen by *Reuters*, NPCIL considers that Kakrapar-4 “would reach completion by March, 2024”.
See Sudarshan Varadhan, “Operation of Fourth Nuclear Power Unit in Gujarat’s Kakrapar Delayed”, *Reuters*, 31 March 2022, see https://www.reuters.com/world/india/operation-nuclear-power-unit-indias-western-gujarat-state-delayed-2022-05-31/, accessed 8 November 2023.

44 - Further delayed.
See Department of Atomic Energy and Rajya Sabha, “Unstarred Question No. 3842—Status of New Nuclear Power Plants”, answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions, Prime Minister’s Office, Government of India, 6 April 2023, see https://cdnbbsr.s3waas.gov.in/s35b8e4fd39d9786228649a8a8bec4e008/uploads/2023/04/2023041254.pdf.
See also note on Kudankulam-5.

45 - Delayed. Ibidem.

46 - Expected construction duration of Kudankulam-5 is 66 months.
See Department of Atomic Energy and Lok Sabha “Unstarred Question No.2756—Kudankulam Nuclear Power Plant”, answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions, Prime Minister’s Office, Government of India, 10 March 2021, see https://dae.gov.in/writereaddata/lsusq%202756.pdf, accessed 30 June 2021.

47 - In March 2022, the Indian government announced that the “project completion schedule” for the four reactors under construction at Kudankulam are “likely to be impacted” because “components and equipments to be imported from Ukraine and Russia may be delayed due to the logistical and ocean freight problems” arising from the war on Ukraine.
See Department of Atomic Energy and Rajya Sabha, “Unstarred Question No. 3286—Status of Work at Kudankulam Power Plant”, answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions, Prime Minister’s Office, Government of India, 31 March 2022, see http://dae.gov.in/writereaddata/rsusq3286.pdf, accessed 7 April 2022.

48 - The expected construction duration of Kudankulam-6 is 75 months.
See Department of Atomic Energy, “Lok Sabha - Unstarred Question No.2756 to be answered on 10.03.2021- Kudankulam Nuclear Power Plant”, Government of India, op. cit.

49 - See note on Kudankulam-5.

50 - Further delayed. Completion now expected in December 2024, compared to September 2024 in WNISR2022.
See Project Monitoring Division, “448th Flash Report on Central Sector Projects (Rs. 150 crore and above)”, Ministry of Statistics and Programme Implementation and Infrastructure, Government of India, March 2023, see http://www.cspm.gov.in/english/flr/FR_March_2023.pdf, accessed 8 November 2023.

51 - Further delayed. Completion is expected in 2026 (compared to June 2023 in WNISR2022).
See Department of Atomic Energy and Rajya Sabha, “Unstarred Question No. 3842—Status of New Nuclear Power Plants”, Government of India, 6 April 2023, op. cit.
As of 1 September 2023, the “Expected Date of Commercial Operation” is “under review” on NPCIL’s dedicated webpage.

52 - Further delayed. Completion is expected in 2026 (compared to December 2023 in WNISR2022).
See Department of Atomic Energy and Rajya Sabha, “Unstarred Question No. 3842—Status of New Nuclear Power Plants”, Government of India, 6 April 2023, op. cit.
As of 1 September 2023, the “Expected Date of Commercial Operation” is “under review” on NPCIL’s dedicated webpage.

53 - Original construction of Bushehr-2 had started in February 1976 before it was halted in 1978. The reactor remained listed as “under construction” in PRIS-IAEA, “Nuclear Power Reactors in the World”, until the 1994 edition. Currently, PRIS indicates September 2019 as construction start, when construction work resumed, and a new concrete slab was poured.

See WNISR, “Iran: Construction Restart of Busheer-2”, 14 November 2019, see https://www.worldnuclearreport.org/Iran-Construction-Restart-of-Busheer-2.html, accessed 8 November 2023.

54 - 2024 is the date announced when construction resumed. However, as of June 2022, *Nuclear Engineering International* mentions a 28-month delay on the construction project, without precisions if this only applies to Unit 3, where no concrete pouring has taken place yet.
See *NEI Magazine*, “Iran begins concrete pouring for wall at Bushehr 2”, 28 June 2022, see https://www.neimagazine.com/news/newsiran-begins-concrete-pouring-for-wall-at-bushehr-2-9806133, accessed 7 July 2022.

55 - Construction status unclear. 2025 used for WNISR projections.

56 - Rosatom, “ROSATOM starts construction of unique power unit with BREST-OD-300 fast neutron reactor”, Press Release, 8 June 2021, see https://rosatom-europe.com/press-centre/news/rosatom-starts-construction-of-unique-power-unit-with-brest-od-300-fast-neutron-reactor/, accessed 19 August 2022.

57 - Further delayed. Start-up date of Kursk 2-1 and 2-2 at construction start was never very explicit, with 2022 often quoted for Unit 1, while others used 2023. However, in the 2019 edition of IAEA’s “Nuclear Power Reactors in the World”, Kursk 2-1 is the only ‘Construction Start During 2018’ to have a grid connection date, set to June 2022. In the 2022 edition, Kursk 2-1 was listed in the “Scheduled connections to the grid during 2022”. The 2023 edition uses March 2025 as grid connection date.

58 - Delayed. In the 2020 edition of IAEA’s “Nuclear Power Reactors in the World”, Kursk 2-2 is the only ‘Construction Start During 2019’ to have a grid connection date, set to December 2023. The 2023 edition of IAEA’s “Nuclear Power Reactors in the World” uses March 2027 as grid connection date for Kursk 2-2.

59 - In August 2022, Rosatom announced the keel-laying ceremony in China of the first Arctic-type Nuclear Floating Power Unit (NFPU) to be equipped with two RITM-200C reactors and to be deployed in Russia. As there is no official name yet for the reactors, those units are provisionally named Cape Nagloynyn 1-1 and 1 -2 according to the overall project name Cape Nagloynyn.
See Rosatom, “Keel-laying ceremony for the first Arctic-type Floating Power Unit with RITM-200 transport reactor vessels”, Press Release, 30 August 2022, see https://rosatom-mena.com/press-centre/news/keel-laying-ceremony-for-the-first-arctic-type-floating-power-unit-with-ritm-200-transport-reactor-v/, accessed 5 October 2022, and *WNN*, “Construction starts on Russia’s next floating nuclear power plant”, *World Nuclear News,* 31 August 2022, see https://www.world-nuclear-news.org/Articles/Construction-starts-on-Russia-s-next-floating-nucl, accessed 20 September 2022.

60 - Further delayed. In August 2022, the Ministry of Economy, stated that “the start-up of the fourth unit of the Mochovce nuclear power plant could be put into operation in approximately 21 months, i.e. in the spring of 2024”.
See MHSP, “Tretí blok v Mochovciach realitou, pokryje až 13 % z celkovej potreby elektriny Slovenska”, Press Release (in Slovak), Ministerstvo hospodárstva Slovenskej republiky/Ministry of Economy of the Slovak Republic, 25 August 2022, see https://www.economy.gov.sk/top/treti-blok-v-mochovciach-realitou-pokryje-az-13-z-celkovej-potreby-elektriny-slovenska?csrt=12344435397304283000, accessed 3 June 2023.

61 - Further delayed. As of September 2023, KHNP’s page had not been updated, still announcing Commercial operation in September 2023 (compared to July 2023 in WNISR2022), with fuel loading in January 2023, which had not happened. Fuel loading was completed in September 2023.
See KHNP, “Nuclear Power Construction—Shin-Hanul #1,2”, Korea Hydro & Nuclear Power, Various Dates, see https://cms.khnp.co.kr/eng/contents.do?key=524, last accessed September 2023; and *WNN* “Fuel loading completed at second Shin Hanul unit”, 20 September 2023, see https://www.world-nuclear-news.org/Articles/Fuel-loading-completed-at-second-Shin-Hanul-unit, accessed 8 November 2023.

62 - In late 2022, two reactors under construction,Shin-Kori Unit 3 and 4, were renamed Saeul-1 and -2.
See KHNP, “Saeul NPP Renames as Saeul Units 1, 2, 3 and 4”, Press Release, Korea Hydro & Nuclear Power, 1 November 2022, see https://cms.khnp.co.kr/eng/selectBbsNttView.do;WCN_KHNPHOME=30yVBQtmOX8ttEVoH9XYo11xjJSy2XlO2nToY1Bf0061D01j_Acf!-1320158464?key=565&bbsNo=84&nttNo=46397&searchCtgry=&searchCnd=all&searchKrwd=&integrDeptCode=&pageIndex=1, accessed 3 November 2022.

63 - Further delayed. Construction officially started in April 2017, suspended in July to resume in October of the same year. Commercial operation at construction start was October 2021; after numerous delays, it is now expected in October 2024 (compared to March 2024 in WNISR2022).
See KHNP, “Nuclear Power Construction – Saeul #3,4”, Korea Hydro & Nuclear Power, Various Dates, see https://cms.khnp.co.kr/eng/contents.do?key=525, last accessed September 2023.

64 - Further delayed. Commercial operation has been pushed back to October 2025 (compared to March 2025 in WNISR2022)
See KHNP, “Nuclear Power Construction—Saeul #3,4”, Korea Hydro & Nuclear Power, Various Dates, see https://cms.khnp.co.kr/eng/contents.do?key=525, last accessed September 2023.

65 - Delayed. The Akkuyu reactors are officially to be completed one per year starting in 2023.
In March 2019, the project management announced that it had finished the concreting of the basemat for the nuclear island and that it was now expected that Akkuyu-1 would be physically completed in 2023, with generation coming at a later date.
See Phil Chaffee, “New Build, Revised 2023 Milestone for Akkuyu”, *Nuclear Intelligence Weekly*, 29 March 2019.
WNISR uses 2024.
The first fuel for the reactor was delivered at the end of April 2023. While stressing that the contractual deadline for the commissioning of Unit 1 is 2025, Rosatom keeps saying that “the project stakeholders are making their best efforts to ensure the readiness for start-up and adjustment works on the Unit No. 1 in 2023, a jubilee year for the Republic of Turkey.”
See Akkuyu Nuclear, “First Batch of Fuel Delivered to Akkuyu NPP”, Rosatom, 27 April 2023, see http://www.akkuyu.com/first-batch-of-fuel-was-delivered-to-akkuyu-npp/update, accessed 29 April 2023.

66 - The Akkuyu reactors are officially to be completed one per year starting in 2023, and official startup date is often quoted as 2024.
See *Daily Sabah*, “Construction starts on 2nd unit of Turkey’s 1st nuclear power plant Akkuyu”, 28 June 2020, see https://www.dailysabah.com/business/energy/construction-starts-on-2nd-unit-of-turkeys-1st-nuclear-power-plant-akkuyu, accessed 28 June 2020.
However, WNISR keeps a 5-year construction time, and a one-per-year startup frequency, beginning with Akkuyu-1 in 2024.

67 - See previous note.

68 - See previous note.

69 - Delayed. No information on a new start-up date for Barakah-4.

70 - WNISR, "The Oddly Discreet Construction Start of Hinkley Point C", 29 December 2018, see https://www.worldnuclearreport.org/The-Oddly-Discreet-Construction-Start-of-Hinkley-Point-C.html, accessed 24 August 2019.

71 - Delayed several times. According to EDF, in May 2022 "the risk of further delay of the two units is assessed at 15 months, assuming the absence of a new pandemic wave and no additional effects of the war in Ukraine". This risk estimate was explicitly confirmed in June 2023, without modification of the the target schedule.
See EDF Group, "Half-Year Financial Report at 30 June 2023", June 2023, see https://www.edf.fr/sites/groupe/files/2023-07/2023-07-27-half-year-results-financial-report.pdf, accessed 8 November 2023.

72 - See WNISR, "Strangely Belated Announcement of Hinkley Point C-2 Construction Start", 18 March 2020, see https://www.worldnuclearreport.org/Strangely-Belated-Announcement-of-Hinkley-Point-C-2-Construction-Start.html.

73 - Delayed several times. See Note on Hinkley Point C-1.

74 - Probably further delayed. Vogtle-4 is projected to enter service "in late fourth quarter 2023 or first quarter 2024", compared to "fourth quarter 2023" in WNISR2022.
See Georgia Power, "Vogtle 3 & 4 nuclear units take significant steps toward operations", Press Release, 1 April 2023, see https://www.prnewswire.com/news-releases/vogtle-3--4-nuclear-units-take-significant-steps-toward-operations-301787633.html, accessed 1 April 2023.

ANNEX 4 – ABBREVIATIONS

ELECTRICAL AND OTHER UNITS

KW	kilowatt (unit of installed electric power capacity)
kWh	kilowatt hour (unit of electricity production or consumption)
MW	megawatt (10^6 watts)
MWe	megawatt electric (as distinguished from megawatt thermal, MWt)
GW	gigawatt (109 watts)
GWe	gigawatt electric
TWh	terawatt hour (10^{12} watt-hours)
Bq	Becquerel
TBq	Terabecquerel
mSv	millisievert
Sv	Sievert
Sv/h	Sievert per hour

ACRONYMS

3/11	"Great East Japan Earthquake"; beginning of the Fukushima nuclear disaster (11 March 2011)
ABWR	Advanced Boiling Water Reactor (Reactor design)
AGR	Advanced Gas-cooled Reactor
AHWR	Advanced Heavy Water Reactor
ALPS	Advanced Liquid Processing Systems
ANC	African National Congress (Political Party, South Africa)
ASN	*Autorité de Sûreté Nucléaire* – Nuclear Safety Authority (France)
BNDES	*Banco Nacional de Desenvolvimento Econômico e Social* – Brazilian Development Bank
BRL	Brazilian real (Currency)
BWR	Boiling Water Reactor (Reactor design)
CAD	Canadian dollar (Currency)
CANDU	CANadian Deuterium Uranium (Reactor design, Canada)
CAREM	Central Argentina de Elementos Modulares – Small Modular PWR Design (under construction in/by Argentina)
CDU	*Christlich Demokratische Union Deutschlands* (Political Party, Germany)
CEFR	China Experimental Fast Reactor
CfD	Contract for Difference
CFPP	Carbon Free Power Project (Small Modular Reactor project, United States)
CGN	China General Nuclear Power Corporation
CNEA	*Comisión Nacional de Energía Atómica* – National Atomic Energy Commission (Argentina)
CNEN	*Comissão Nacional de Energia Nuclear* – Federal Commission on Nuclear Energy (Brazil)
CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
COL	Construction and Operating License (United States)
COP	Conference of the Parties (of the United Nations Framework Convention on Climate Change)

CSU	*Christlich-Soziale Union* – Christian Social Union (Political Party, Bavaria, Germany)
DC	Design Certification
DIW	*Deutsches Institut für Wirtschaftsforschung e.V.* – German Institute for Economic Research
[U.S.] DOE	Department of Energy (United States)
EDF	*Électricité de France* – State-owned Power Utility (France)
EIA	Environmental Impact Assessment or Energy Information Administration (United States Department of Energy)
EL-4	Reactor (France)
ENBPar	*Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A* (state-controlled company, Brazil)
EnBW	*Energie Baden-Württemberg AG* (Energy Company, Germany)
Enresa	*Empresa Nacional de Residuos Radiactivos S.A.* – Radioactive Waste Management Agency (Spain)
EPACT	Energy Policy Act (U.S. Federal legislation, 2005)
EPC	Engineering, Procurement and Construction
EPR	European Pressurized Water Reactor or Evolutionary Power Reactor (Reactor Design)
E.U.	European Union
EXIM	Export-Import Bank (United States)
FBR	Fast Breeder Reactor
FDP	*Freie Demokratische Partei* – Free Democratic Party (Germany)
FERC	Federal Energy Regulatory Commission (United States)
FID	Final Investment Decision
FL3	Flamanville-3 (Reactor, France)
FOAK	First-of-a-Kind
GBN	Great British Nuclear (United Kingdom)
GCR	Gas-Cooled Reactor
GEH	GE Hitachi
GEN III	Generation III – "Advanced" Nuclear Power Reactor designs
GHG	Greenhouse Gas
HB	House Bill (United States)
HDR	*Heißdampfreaktor* (Reactor, Germany)
HPC	Hinkley Point C (Reactor, United Kingdom)
HTGR	High Temperature Gas Cooled Reactor
HTR	High Temperature (Gas-Cooled) Reactor
HTR	High Temperature Reactor
HTR-PM	High-Temperature gas-cooled Reactor Pebble-bed Module (Demonstration plant, China)
IAEA	International Atomic Energy Agency
IIJA	Infrastructure Investment and Jobs Act (U.S. Federal legislation, 2021)
IRA	Inflation Reduction Act (U.S. Federal legislation, 2022)
IRENA	International Renewable Energy Agency
ITAAC	Inspections, Tests, Analyses, and Acceptance Criteria (Licensing standards, United States)
JAIF	Japan Atomic Industrial Forum
JPDR	Japan Power Demonstration Reactor
JSW	Japan Steel Works (company, Japan)

KEPCO	Kansai Electric Power Company (Japan) or Korea Electric Power Corporation (South Korea)
KHNP	Korea Hydro & Nuclear Power (operator, subsidiary of Korea Electric Power Corporation, South Korea)
KRW	Korean won (Currency)
LTE	Long-Term Enclosure
LTO	Long-Term Outage
LWR	Light Water Reactor
METI	Ministry of Economy, Trade and Industry (Japan)
MIT	Massachusetts Institute of Technology (United States)
MoU	Memorandum of Understanding
MOX	Uranium-plutonium Mixed-OXide
NDC	Nationally Determined Contribution (under the Paris Agreement)
NEA	National Energy Administration (China) or Nuclear Energy Agency (of the Organisation for Economic Co-operation and Development)
NOAK	Nth-of-a-Kind
NPP	Nuclear Power Plant
NPT	Treaty on the Non-Proliferation of Nuclear Weapons (1968)
NRA	Nuclear Regulatory Authority (Japan)
[U.S.] NRC	United States Nuclear Regulatory Commission
OCC	Overnight Capital Costs
OECD	Organisation for Economic Co-operation and Development
OL3	Olkiluoto-3 (Reactor, Finland)
ONR	Office for Nuclear Regulation (United Kingdom)
OPG	Ontario Power Generation (Company, Canada)
PBMR	Pebble Bed Modular Reactor (Reactor design, South Africa)
PEJ	*Polskie Elektrownie Jądrowe* – State-owned company (former PGE EJ1, Poland)
PG&E	Pacific Gas and Electric Company (United States)
PGE	*Polska Grupa Energetyczn* – Polish Energy Group (Company, Poland)
PRIS	Power Reactor Information System (of the International Atomic Energy Agency)
PTC	Production Tax Credit
PV	Photovoltaics
PWR	Pressurized Water Reactor (Reactor type)
RAB	Regulated Asset Base
RBMK	*Reaktor Bolshoy Moshchnosti Kanalnyi* (Soviet reactor design)
RITM	Russian reactor design (Generation III+)
RTE	*Réseau de Transport d'Électricité* – Transmission System Operator (France)
RWE	*Rheinisch-Westfälisches Elektrizitätswerk* – Rhine-Westphalia Power Utility (Germany)
SDA	Standard Design Approval
SMR	Small Modular Reactor
TEPCO	Tokyo Electric Power Company (Japan)
THTR	Thorium High Temperature Reactor (Reactor, Germany)
TMI	Three Mile Island (Nuclear Power Plant, United States)
TVA	Tennessee Valley Authority

U.K.	United Kingdom
U.S.	United States of America
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change
US$	U.S. dollar (Currency)
VD	*Visite Décennale* – Decennial Safety Review (France)
VVER	*Vodo-Vodianoï Energuetitcheski Reaktor* (Russian Pressurized Water Reactor design)
WIP	*Fachgebiet Wirtschafts- und Infrastrukturpolitik* – Workgroup for Economic and Infrastructure Policy (of the Technical University of Berlin, Germany)
WNA	World Nuclear Association
WNISR	World Nuclear Industry Status Report
WNN	*World Nuclear News* (publication of the World Nuclear Association)
ZAR	South African rand (Currency)

ANNEX 5 – ABOUT THE AUTHORS

Stephanie Cooke is an opinion writer for *Energy Intelligence* and writes occasional articles for mainstream media. She helped launch *Nuclear Intelligence Weekly* in 2007 and was its editor until 2022, overseeing global coverage of the commercial nuclear industry, and delivering news and analysis of key industry sectors. She helped frame discussions of the broader technical, commercial, and international policy issues confronting the industry at conferences and other forums, including for the Institute of Nuclear Materials Management. Her history of the intertwined development of nuclear weapons and nuclear power, "In Mortal Hands: A Cautionary History of the Nuclear Age", was published in 2009. She has been interviewed by numerous television and radio programs in the United States and overseas, and participated in podcasts about nuclear energy. Stephanie Cooke began her journalism career at *The Associated Press* and then began covering the nuclear industry for *Nucleonics Week*, *Nuclear Fuel*, and *Inside NRC*.

Antony Froggatt joined Chatham House in 2007 where he is Senior Research Fellow and Deputy-Director of the Environment and Society Centre. He studied energy and environmental policy at the University of Westminster and the Science Policy Research Unit at Sussex University. For over 20 years he has been involved in the publication of the World Nuclear Industry Status Report (WNISR). At Chatham House, he specializes on global electricity policy and the geopolitics of the energy transition. He has worked as an independent consultant for two decades with environmental groups, academics and public bodies in Europe and Asia. His most recent research project is understanding the energy and climate policy implications of the Russian invasion of Ukraine.

Julie Hazemann, based in Paris, France, is the Director of EnerWebWatch, an international documentation monitoring service, specializing in energy and climate issues, launched in 2004. As an information engineer and researcher, she has maintained, since 1992, a world nuclear reactor database and undertakes data-modelling and data-visualization work for the World Nuclear Industry Status Report (WNISR). Active in information and documentation project-management, she has a strong tropism for information structuration, dataviz and development of electronic information products. She also undertakes specialized translation and research activities for specific projects. She is a member of négaWatt (France) and develops EnerWebWatch in the framework of the Coopaname Coop.

Christian von Hirschhausen is Professor of Economics at the Workgroup for Economic and Infrastructure Policy (WIP) at Berlin University of Technology (TU Berlin), and Research Director at DIW Berlin (German Institute for Economic Research). He obtained a PhD in Industrial Economics from the Ecole Nationale Supérieure des Mines de Paris and was previously Chair of Energy Economics and Public Sector Management University of Technology (TU Dresden). Von Hirschhausen focuses on the regulation and financing of infrastructure sectors, mainly energy, and is a regular advisor to industry and policymakers, amongst them the World Bank, the European Commission, European Investment Bank, and several German Ministries. Von Hirschhausen also focusses on energy technologies and is one of the coordinators of a research project on nuclear energy in Germany, Europe, and abroad, including the first independent monitoring of the decommissioning process of German nuclear power plants.

Timothy Judson is an independent consultant who provides industrial and policy analysis, with over twenty years of experience in the United States. He has published several reports on the nuclear energy industry and energy and climate policy, including "Nuclear Power and Climate Change: An Assessment for the Future" and "Too Big to Bail Out: The Cost of a National Nuclear Energy Subsidy." Since 2014, he has served as the Executive Director of Nuclear Information and Resource Service, a non-profit environmental organization based in the United States. He lives in Syracuse, New York.

Doug Koplow is the founding director of Earth Track in Cambridge, MA. For more than three decades, he has worked with environmental groups and international agencies to identify and measure environmentally harmful subsidies to natural resource extraction, and to document their pervasive reach and enormous scale. His work has included detailed reviews of government support to the nuclear fuel chain, highlighting the many ways governments support the industry and shift business risks onto taxpayers. He holds an MBA from Harvard Business School and a BA in economics from Wesleyan University.

Arnaud Martin, webdesigner and full-stack developer, initiated the development of the CMS SPIP in 2000, and launched the social network Seenthis.net in 2009. His work can be seen on 23FORWARD.

Friedhelm Meinaß, born in 1948, is a visual artist and painter based in the Frankfurt area, Germany. His characteristic pieces including his cover art for Nina Hagen, are on display in the German History Museum in Berlin, and his work is internationally acclaimed. Amongst others, Meinaß has cooperated with Leonard Bernstein, The Byrds, Johnny Cash, Vladimir Horowitz and Billy Joel. He is collaborating with the Designer Constantin E. Breuer, who congenially implements his ideas. Meinaß held a professorship at the University of Design in Darmstadt in the early 1970s.

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Nina Schneider is a freelance proofreader and translator with Coopaname, Paris, France. Her involvement with the World Nuclear Industry Status Report dates back to 2014 and has been evolving ever since, adding fact checking, background research, and various production tasks to her responsibilities.

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Agnès Stienne is a freelance artist, cartographer and graphic designer. She worked for over ten years as a cartographer for the French newspaper *Le Monde Diplomatique*. For several years now, she has been leading a research project focusing on agricultural practices, "land grabbing" and other fundamental issues related to agriculture and food. This work takes the form of "geo-poetic" narratives published on the cartographic experimentation website Visioncarto.net. Among these, she produced a series of paintings based on satellite images from Google Earth as a continuation of "Géographie du palmier à huile ", exhibited in Le Mans (France) in 2020 and 2021. In 2023, she published "Bouts de bois - Des objets aux forêts", a free and sensitive essay with *Éditions La Découverte*, Zones collection.

Tatsujiro Suzuki is a Vice Director, Professor of Research Center for Nuclear Weapons Abolition at Nagasaki University (RECNA), Japan. Before joining RECNA, he was a Vice Chairman of Japan Atomic Energy Commission (JAEC) of the Cabinet Office from January 2010 to March 2014. Until then, he was an Associate Vice President of the Central Research Institute of Electric Power Industry (CRIEPI) in Japan (1996–2009) and Visiting Professor at the Graduate School of Public Policy, University of Tokyo (2005–2009), an Associate Director of MIT's International Program on Enhanced Nuclear Power Safety from 1988–1993 and a Research Associate at MIT's Center for International Studies (1993–1995). He is a member of the Advisory Board of Parliament's Special Committee on Nuclear Energy since June 2017. He is also a Council Member of Pugwash Conferences on Science and World Affairs (2007–2009 and from 2014~), Co-Chair of the International Panel on Fissile Materials (IPFM) and a Board member of Asia Pacific Leadership Network for Nuclear Non-Proliferation and Disarmament (APLN). Dr. Suzuki has a PhD in nuclear engineering from Tokyo University (1988).

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Hartmut Winkler is a Professor in the Department of Physics of the University of Johannesburg in South Africa. After completing his PhD in Astronomy at the University of Cape Town, he joined the Soweto Campus of the former Vista University, where he started engaging in air quality research, which led to an interest in solar irradiance studies, solar energy potential and later energy studies in the broader sense. After a stint in the University administration as Dean of Science, he returned to scientific work after joining the new University of Johannesburg. In recent years, he has been one of South Africa's most visible television and radio commentators on the country's electricity crisis. His contributions include numerous media articles on topics focusing on nuclear energy in South Africa.