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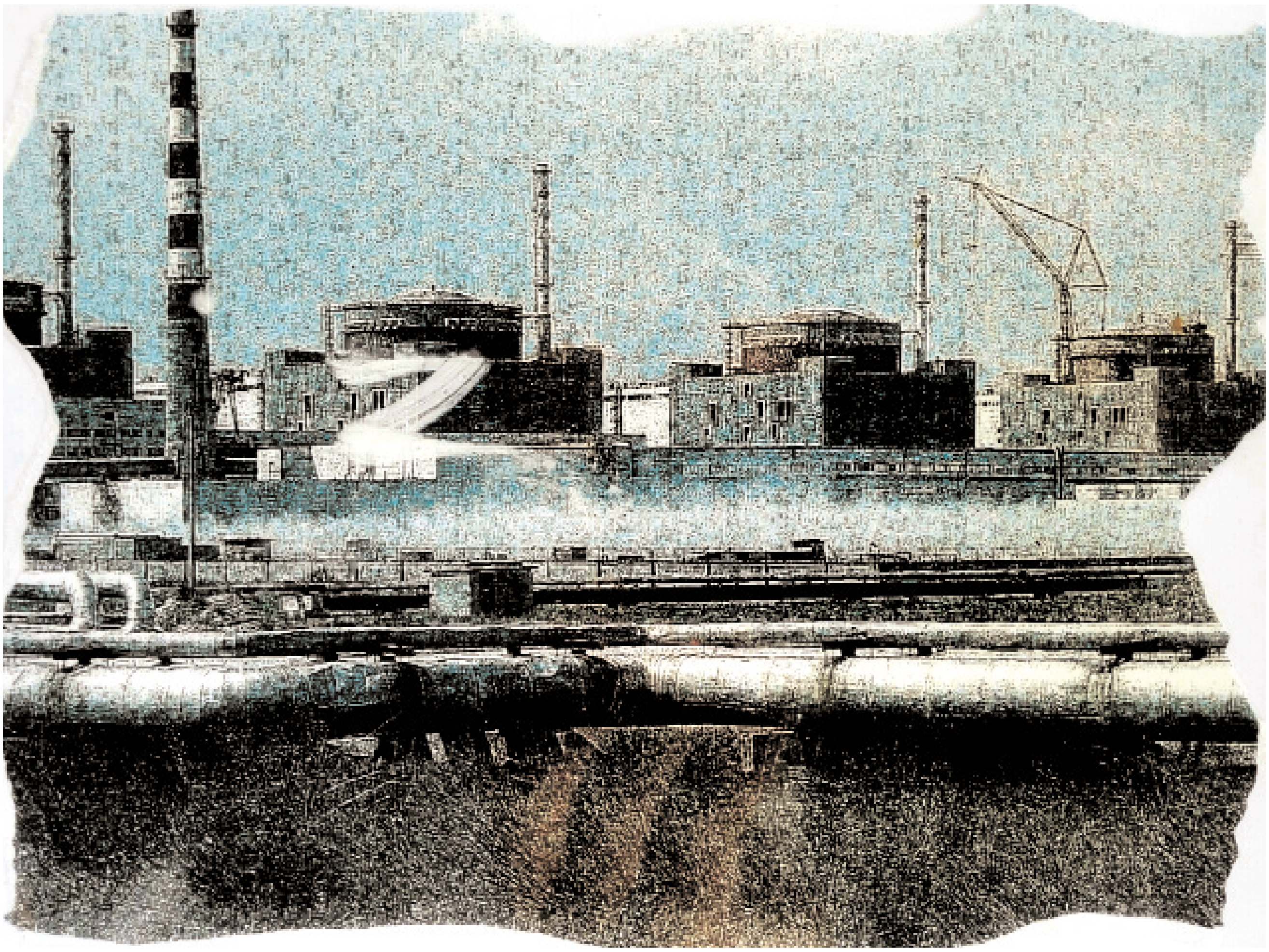
The World Nuclear Industry
Status Report 2022



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The World Nuclear Industry
Status Report 2022

Foreword by

Aviel Verbruggen
Prof. Dr. Emeritus, University of Antwerp, Belgium

By

Mycle Schneider
Independent Consultant, Paris, France
Project Coordinator and Lead Author

Antony Froggatt
Independent Consultant, and Deputy Director and Senior Research Fellow, Environment and Society Programme, Chatham House, London U.K.
Lead Author

With

Julie Hazemann
Director of EnerWebWatch, Paris, France
Documentary Research, Modelling and Datavisualization

M.V. Ramana
Simons Chair in Disarmament, Global and Human Security at the School of Public Policy and Global Affairs (SPPGA), University of British Columbia, Vancouver, Canada
Contributing Author

Michael Sailer
Independent Consultant, Former Chairman of the Reactor Safety Commission and Former CEO of Oeko-Institut, Darmstadt, Germany
Contributing Author

Tatsujiro Suzuki
Vice Director, Research Center for Nuclear Weapons Abolition, Nagasaki University (RECNA), Former Vice-Chairman of the Japan Atomic Energy Commission, Japan
Contributing Author

Christian von Hirschhausen
Professor, Workgroup for Economic and Infrastructure Policy, Berlin University of Technology (TU) and Research Director, German Institute for Economic Research (DIW), Berlin, Germany
Contributing Author

Alexander James Wimmers
Research Associate at the Workgroup for Economic and Infrastructure Policy (WIP), Berlin University of Technology (TU), Berlin, Germany
Contributing Author

Nina Schneider
Proofreading, Fact-Checking, Production, Translation, Paris, France
Proofreading and Production

Agnès Stienne
Artist, Graphic Designer, Cartographer, Le Mans, France
Graphic Design and Layout

Friedhelm Meinass
Visual Artist, Painter, Rodgau, Germany
Cover-page Design, Painting and Layout

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The first thing to say is simply a huge, I mean a huge, huge thank you to the team that put the WNISR2022 together. The project has survived unfavorable if not adverse conditions for 15 years, but this year was simply unprecedented. For health and career reasons, several core contributing authors unexpectedly were not able to provide input this year. But… the extraordinary solidarity of the remaining team and a couple of exceptional contributors who together picked up the tab made it possible to produce this report together against all odds.

It has been 30 years that we produced a precursor WNISR. It has been 30 years that my friend Antony Froggatt has been a solid partner in developing the report concept, contributing chapters, editing others, and presenting the outcome. Thank you for everything.

At the core of the WNISR is its database designed and maintained by data manager and information engineer Julie Hazemann who also develops most of the drafts for the graphical illustrations and manages much of the cooperation with designer and webmaster. She expanded her contribution significantly over the past few years. As ever, no WNISR without her. Thanks so much.

M.V. Ramana, over the years, has not only been a regular, reliable, professional, and insightful contributor but also a wonderful person to work with. Heartful thanks.

Very glad to count Tatsu Suzuki amongst the core team, following decades of cooperation under various circumstances and organizational arrangements. Thank you very much for your invaluable contributions.

Very happy to work with Michael Sailer again with whom I have crossed paths for some four decades now. Thank you for your crucial, timely contribution to this project.

Christian von Hirschhausen, thank you for being back on the project. Your constructive thinking and positivity are a real treat. Newcomer Alex Wimmers dived into the WNISR with skill and full engagement. Thank you and see you both next year!

Nina Schneider has further expanded her meticulous proof-reading, source verification, and fact-checking capacities. This year, she also drafted several sections of the report. Her production skills are indispensable to the outcome. Merci beaucoup.

Special thanks go to Tim Judson and another expert who not only filled in unexpected gaps but superbly mastered the tasks under impossible time constraints.

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Artist and graphic designer Agnès Stienne created the redesigned layout in 2017 and is constantly improving our graphic illustrations that continue to get the praise they deserve around the world. Thank you once again.

A big thank you also to Arnaud Martin for his continuous, highly reactive, and reliable work on the website www.WorldNuclearReport.org, dedicated to the WNISR Project.

For the fourth time in a row, we owe idea, design, and realization of the report-cover to renowned German painter Friedhelm Meinass and designer Constantin E. Breuer, ("who congenially implements my ideas", dixit F.M.). Thanks so much for another striking, politically intelligent, and very generous contribution.

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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.

Lead Authors' Contact Information

Mycle Schneider
45, Allée des Deux Cèdres
91210 Draveil (Paris) France
Ph: +33-1-69 83 23 79
E: mycle@WorldNuclearReport.org

Antony Froggatt
53a Neville Road
London N16 8SW United Kingdom
Ph: +44-79 68 80 52 99
E: antony@froggatt.net

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FOREWORD

by Aviel Verbruggen[1]

When you read these words, you have found the way to the world's unique source of knowledge about the nuclear industry. The independent 'coordinating lead authors',[2] Mycle Schneider and Antony Froggatt, compose the WNISR annually since 2007. Their rigorous, perseverant work has grown the scope and impact. The yearly editions provide the essential statistical series for a reliable assessment of the industry's status, complemented with chapters exploring topical issues.

Consistent and transparent data series, updated until mid-2022, gives us a comprehensive and longitudinal perspective of the global industry. As usual, the text is illustrated with tables and figures, making the contents more accessible in shorter time, with reading even more pleasant. After the status of the global industry, we as readers are spoiled with a richness of information about the status of the nuclear industry in various nations and from various angles. The ten focus countries got a specific analysis in relation to the specific issues affecting their nuclear businesses. For example, for France, a specific section on "Nuclear Unavailability" provides all information you would like to assess the gravity of this problem. In addition to the ten focus countries, WNISR2022 holds a 75 pages Annex 1 with an Overview by Region and by Country. None escape from the scrutiny of the WNISR team. Further, the topical chapters cover, on the one hand, two thorny issues (Fukushima Status, and Decommissioning Status), on the other hand, two anticipatory issues (Potential Newcomer Countries, and Small Modular Reactors). The sobering approach of the issues by the WNISR team is enormously welcome in a world overridden by flawed and deceiving news.

In 2022, for the first time, there is a chapter on "Nuclear Power and War", prompted by the war in Ukraine. First, the authors painstakingly discuss higher loss-of-coolant risks in nuclear reactors and in spent fuel ponds. Invading and defending combatants likely increase the probability of such loss and hinder fast and full emergency interventions. Second, the situation in Ukraine is documented by a selection of official statements by the International Atomic Energy Agency (IAEA) and the State Nuclear Regulatory Inspectorate of Ukraine, chronologically over the period 24 February–13 September 2022. Timely, yet frightening, information. The authors refrain from any comments on these statements, acknowledging that either source is not unbiased, and that truly independent sources of information on the situation at the Ukrainian nuclear facilities simply do not exist.

Valuable academic research depends on accurate data, unbiased information, and on the independent disposition of the researcher. For issues of global importance, such as climate change and related energy use, the worldwide involvement of scientists enhances diversity and quality of the research and its products. *Free access* to data and documents is vital for the participation of scientists who do not enjoy wealthy college privileges. In my energy research, I use BP Statistical Reviews, IRENA reports, and WNISRs, for data and information about respectively fossil fuels, renewable energy sources and technologies, and nuclear affairs. The three are open access. BP is a superrich oil major. IRENA is financed by national governments.

1 - Prof. Dr. Emeritus, University of Antwerp, Belgium, for details see https://www.avielverbruggen.be.

2 - Phraseology used by the Intergovernmental Panel on Climate Change (IPCC).

WNISR thrives by the seemingly inexhaustible energy of the coordinating lead authors, boosted by contributions from several independent scientists and a few sponsors.

The WNISR is in good hands, guaranteeing ever improving reports. However, the longevity of the nuclear industry, and certainly of its legacy, encourages the consideration of a more robust WNISR financing and/or a stable institutional framework.

One of the observed flaws in the international regulation of the nuclear sector, is the double mission of the IAEA: on the one hand, reduce the proliferation of nuclear weaponry, and on the other hand, promote the proliferation of nuclear power generation. Once, a nation acquires the knowledge and technologies of nuclear power, it is capable of building atomic bombs. I support the recommendation that the governments of the world categorically dissolve the IAEA's double role and limit IAEA tasks to control and enforcement of the Non-Proliferation Treaty, and to care for the nuclear legacy. A multiple win: finally, the IAEA would fully focus on minimizing proliferation; the high spending on propaganda for nuclear power would be reduced; and the Intergovernmental Panel on Climate Change (IPCC)[3] Working Group 3 (WG3) "nuclear-gate" would be closed.

The IPCC assessment reports[4] encompass three volumes, realized by three WGs. WG1 is phenomenal in assessing all available climate science. WG2 is less comprehensive because climate change impacts it assesses are many, diverse, and not fully inventoried. WG3 covers mitigation options, and it is problematic because of the influence of neoclassical economics, neoliberal viewpoints, incumbent interests. A salient case is how WG3 assesses the literature on nuclear power. The nuclear sections[5] are skipping most of the peer-reviewed literature on nuclear performance, on its degree of sustainability, its compatibility with renewable power from sun and wind. The sections depend on nuclear sector non-peer reviewed literature of the IAEA, the Nuclear Energy Agency (NEA), and similar.

The lopsided treatment of such an important subject means a grave infliction on the "Principles Governing IPCC Work, Section 4.3.3", requesting full assessment of the available literature, and "clearly identify disparate views for which there is significant scientific or technical support, together with the relevant arguments". A balanced assessment of the literature on nuclear power would be a formidable challenge for IAEA's nuclear advocacy. It would help to dissolve the juxtaposition "*renewables, nuclear, carbon capture and storage*" as mitigation options.[6] This deceiving triptych mantra retards the transformation of the global energy systems to 100% renewable energy supplies, the substrate for a genuine common future as spelled out in the Brundtland report (1987).

WNISRs are vital reality checks of the nuclear industry's performance. Every yearly report is a barrier against utopian fantasies and wishful thinking, a tool to connect with reality. We count on the perseverance of the WNISR coordinating lead authors, contributing authors, and the entire team.

3 - The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.

4 - See IPCC, "Reports", Intergovernmental Panel on Climate Change, 2022, see https://www.ipcc.ch/reports/.

5 - For example: See IPCC (2019) Global warming of 1.5°C, Ch.4 (section 4.3.1.3, p. 325); IPCC (2022). Sixth Assessment Report WG3, Ch. 6 (section 6.4.2.4, p.6-34 to 6-36).

6 - More detail is available in Aviel Verbruggen, "Pricing Carbon Emissions—Economic Reality and Utopia", 2021, pp.93-97, and pp.106-111.

KEY INSIGHTS

Nuclear Share Drops Below 10 Percent – Official Figures See Reactors/Capacity Peaking in 2018

- Nuclear energy's share of global commercial gross electricity generation in 2021 dropped to 9.8 percent—the first time below 10 percent and the lowest value in four decades—and 40 percent below the peak of 17.5 percent in 1996.
- International Atomic Energy Agency (IAEA) statistics show a peak in officially operating reactors, both in terms of number (449) and capacity (396.5 gigawatt), in 2018. The IAEA's total of 437 reactors "in operation" in the world at the end of 2021 included 23 reactors that have not generated power since 2010–2013.
- As of mid-2022, 411 reactors were operating in 33 countries, four less than a year earlier, seven less than in 1989, and 27 below the 2002-peak of 438.
- Six units were connected to the grid in 2021, of which three were in China. Five new units became operational in the first half of 2022, including two in China.
- Eight reactors were closed in 2021; two additional closures in the U.K. were announced during the year but the units had not generated any power since 2018.
- Over the two decades 2002–2021, there were 98 startups and 105 closures. Of these, 50 startups were in China which did not close any reactors. Thus, outside China, there was a net decline by 57 units over the same period; net capacity dropped by 25 GW.
- Nuclear electricity generation in the world increased by 3.9 percent but remained below the 2019 level. Outside of China, nuclear production increased 2.8 percent to a level similar to 2017.

Russia Dominates the International Market – Construction Delays Worsen

- China has by far the most reactors under construction (21, as of mid-2022) but is not building abroad.
- Russia is dominating the international market with 20 units under construction including 17 units in seven other countries (as of mid-2022). The impact of sanctions and potential other geopolitical developments on these projects is uncertain.
- Construction started on 10 reactors in 2021, including six in China. The other four are implemented by Russia's Rosatom in India (2), in Turkey, and domestically. Two of the construction starts in China were also by Rosatom.
- Two potential newcomer countries had nuclear reactors under construction as of mid-2022: Bangladesh and Turkey. Egypt started construction shortly after. All of these projects are implemented by the Russian nuclear industry.
- Besides Rosatom, only French and South Korean companies are acting as leading contractors building nuclear power plants abroad.
- At least nearly half (26) of the 53 construction projects are delayed. Of these, 14 have reported increased delays and two have indicated first delays over the past year.
- At the beginning of 2021, 16 reactors were scheduled to be connected to the grid during the year, but only six did, the other 10 were delayed at least into 2022.

Fukushima

- The situation onsite and offsite is far from stabilized.
- The safety authority agreed to release over 1.3 million cubic meters of contaminated water into the ocean, which would take at least three decades. Most of the water would have to be treated again before being diluted and released. The plan remains widely contested, both in Japan and overseas.

Noteworthy National Developments

- **China.** Nuclear power generation increased by 11 percent and provided, as in 2020, 5 percent of total electricity production in 2021.
- **Finland.** The first European Pressurized Water Reactor (EPR) on the continent, under construction since 2005, finally started up in March 2022, 13 years later than scheduled.
- **France.** The unexpected detection of stress corrosion cracking in emergency cooling systems led to a massive inspection and repair program on the entire nuclear fleet. The problem adds to extended outages due to other issues. The ensuing decline in electricity generation is expected to lead in 2022 to an annual output level last seen in 1990.
- **India.** Nuclear generation has been declining since 2019 and represented 3.2 percent of total electricity production in 2021. Eight reactors are listed as under construction, including four of Russian design.
- **United States.** Nuclear output peaked in 2019 and had dropped by a cumulated 3.9 percent by 2021; its share of commercial electricity generation declined to 18.9 percent, its lowest level since it reached its maximum in 1995.

Decommissioning

- The number of closed power reactors exceeded 200 for the first time at the end of 2021, reaching 204 units as of mid-2022, eight more than one year earlier.
- Only 22 reactors or 11 percent have been fully decommissioned; of these, only 10 units or 5 percent of all closed reactors have been returned to greenfield sites for unrestricted use.

Nuclear Power and War

- Russia's invasion of Ukraine has led to several unprecedented situations including the operation of commercial nuclear power plants during a full-scale war.
- No nuclear power plant in the world has been designed to operate under wartime conditions.
- The key challenge is to maintain continuous cooling of the reactor core and the spent fuel pool, even after the shutdown of the reactor.
- Failure to evacuate residual decay heat can lead to core meltdown within hours or spent fuel pool fire within days or weeks with potentially large releases of radioactivity.
- Cooling requires an effective chain of elements providing a reliable supply of electricity and water.
- During war, there are many vulnerabilities and potential deliberate as well as accidental impacts, onsite and offsite, that can lead to the interruption of electricity and water supply.
- The operation of a nuclear facility requires motivated, well-rested, and skilled staff, but operators are likely to be under severe stress during a war or when under military occupation.
- Specialists from outside, and spare parts necessary to maintain operations and carry out inspections or repairs at the nuclear plant might not get permission or access to the facility.

Renewable Energy Marginalizes Nuclear Power

- **World.** Investments in non-hydro renewables in 2021 totaled a record US$366 billion adding around 250 gigawatt net to the grids while operating nuclear capacity *decreased* by 0.4 gigawatt. In 2021, wind and solar alone reached a 10.2 percent share of gross power generation, the first time, they provided more than 10 percent of global electricity and surpassed the contribution of nuclear energy.
- **China.** In 2021, renewable-energy-based power generation grew faster than any other energy sources. Wind energy output grew by 40 percent and solar by 25 percent. Wind turbines generated 71 percent more power than nuclear reactors and solar remained just 15 percent short of the nuclear output.
- **India.** In 2021, both wind and solar each contributed more than 150 percent of nuclear to national power generation

EXECUTIVE SUMMARY AND CONCLUSIONS

As much of 2021 has been dominated by the ongoing COVID-19 pandemic, the end of the year saw the beginning of a global energy crisis with unprecedented price levels for natural gas and electricity that will likely impact the well-being of many and the economic systems for years to come. The war in Ukraine dramatically exacerbated the energy crisis and will profoundly alter international geopolitics for the long term. 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 with earlier reports, *The World Nuclear Industry Status Report 2022* (*WNISR2022*) provides a comprehensive overview of nuclear power plant data, including information on age, operation, production, and construction of reactors. But due to the unprecedented situation in Ukraine, WNISR2022 includes a dedicated chapter that assesses the specific challenges and risks of Nuclear Power and War.

WNISR2022 analyses the status of newbuild programs in some of the 33 nuclear countries (as of mid-2022) as well as in potential newcomer countries. WNISR2022 includes sections on ten Focus Countries representing 30 percent of the nuclear countries, two thirds of the global reactor fleet, and four of the world's five largest nuclear power producers.

The Decommissioning Status Report provides an overview of the current state of nuclear reactors 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 sections.

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, and Belarus (both 2020); in 2021, no newcomer country started any reactor. Three countries abandoned their nuclear power programs, Italy (1987), Kazakhstan (1998), and Lithuania (2009).

Reactor Operation and Capacity. As of 1 July 2022, a total of 411 reactors—excluding Long-Term Outages (LTOs)—were operating in 33 countries, four units less than WNISR2021, seven less than in 1989, and 27 below the 2002-peak of 438. The nominal net nuclear electricity generating capacity declined in 2021 over the previous year by 0.4 GW.[7] As of mid-2022,

7 - Six reactor startups +5.2 GW, eight reactor closures -7.6 GW, LTO restarts +1.6 GW, nominal capacity changes (uprating) +0.4 GW = -0.4 GW. Two additional reactor closures were announced in 2021 but they did not generate any power since 2018 and are thus retroactively closed according to WNISR criteria.

operating capacity reached the same level as in mid-2021 at 369 GW, representing a peak just above the 2006-end-of-year record of 367 GW. (This might change at the end of the year.)

IAEA versus WNISR Assessment. International Atomic Energy Agency (IAEA) statistics show a historic peak in officially operating reactors, both in terms of number (449) and capacity (396.5 gigawatt), in 2018. As of December 2021, the IAEA included 33 units in Japan in its total of 437 reactors "in operation" in the world while 23 of these reactors have not produced electricity since 2010–2013 (of which, three since 2007). Again, as of December 2021, WNISR classified 29 units are as LTO, of which 23 in Japan, three in India, two in Canada, and one in South Korea. These 29 reactors are still in LTO status as of mid-2022, and amount to three more than classified in that category in WNISR2021.

Nuclear Electricity Production. In 2021, the world nuclear fleet generated 2,653 net terawatt-hours (TWh or billion kilowatt-hours) of electricity. Nuclear production increased by 3.9 percent in 2021 but remained just below the 2019 level.

China produced more nuclear electricity than France for the second year in a row and remains in second place—behind the United States—for the top nuclear power generators. Outside of China, nuclear production increased 2.8 percent to a level similar to 2017.

Share in Electricity Mix. Nuclear energy's share of global commercial gross electricity generation in 2021 dropped to 9.8 percent—the first time below 10 percent and the lowest value in four decades—and over 40 percent below the peak of 17.5 percent in 1996, as globally electricity generation continues to rise.

REACTOR STARTUPS AND CLOSURES[8]

Startups. Six units were connected to the grid in 2021, of which three were in China, and one each in India, Pakistan (built by China), and the UAE. Five new units became operational in the first half of 2022, including two in China, one each in Finland, Pakistan (built by China), and South Korea.

Closures.[9] Eight reactors were closed in 2021, including three in Germany and one each in Pakistan, Russia, Taiwan, U.K., and U.S. Two additional closures in the U.K. were announced during the year but they had not generated any power since 2018 (thus WNISR retroactively considers them closed since 2018).

Over the two decades 2002–2021, there were 98 startups and 105 closures. Of these, 50 startups were in China which did not close any reactors. As a result, outside China, there has been a drastic net decline by 57 units over the same period; net capacity declined by over 25 GW.

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

9 - 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.

CONSTRUCTION DATA[10]

As of 1 July 2022, 53 reactors (53.3 GW) were considered as under construction, the same number the WNISR reported a year ago, but 16 fewer than in 2013 (five of those units have subsequently been abandoned).

Four in five reactors are built in Asia or Eastern Europe. 15 countries are building nuclear plants, two less (Finland and Pakistan) than in WNISR2021. Only four countries—China, India, Russia, and South Korea—have construction ongoing at more than one site. Since mid-2021, construction started on seven reactors worldwide, including six in China and one in India (Kudankulam-6).

Building vs. Vendor Countries

- As of mid-2022, with 21 units or 40 percent, China has by far the most reactors under construction. However, China is currently not building anywhere outside the country.
- Russia is largely dominating the international market as a technology supplier with 20 units under construction in the world as of mid-2022 of which only three are being built domestically. The remaining 17 units are being constructed in seven countries, including four each in China and India, and three in Turkey.[11] It is uncertain at this point to what extent these projects will be impacted by the sanctions imposed on Russia and other consequential geopolitical developments following the invasion of Ukraine.
- Besides Russia's Rosatom, there are only French and South Korean companies acting as leading contractors building nuclear power plants abroad.

Construction Times

- For the 53 reactors being built, it is an average of 6.8 years has passed since construction started, slightly lower than the mid-2021 average of seven years.
- *All* reactors under construction in at least 10 of the 15 countries have experienced mostly year-long delays.
- At least half (26) of all projects are delayed. Of these, at least 14 have reported *increased* delays and two have reported *new* delays over the past year.
- WNISR2020 noted a total of 19 reactors scheduled for startup in 2021, and at the beginning of 2021, 16 were still planned to be connected to the grid but only six of these made it, while the other 10 were delayed at least into 2022.
- Construction starts of two projects date back 37 years, Mochovce-3 and -4 in Slovakia, and their grid connection has been further delayed. Bushehr-2 in Iran originally started construction in 1976, over 45 years ago, and resumed construction in 2019 with grid connection currently scheduled for 2024.
- Six additional reactors have been listed as "under construction" for a decade or more: 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

10 - See Annex 3 for a detailed overview of the 53 reactors under construction in the world as of mid-2022.

11 - Construction of a fourth unit started at the Akkuyu site in Turkey on 21 July 2022, see WNISR, "Akkuyu-4 in Turkey: Second Construction Start in a Week for the Russian Nuclear Industry—Anyways 4", 24 July 2022, see https://www.worldnuclearreport.org/Akkuyu-4-in-Turkey-Second-Construction-Start-in-a-Week-for-the-Russian-Nuclear.html, accessed 9 September 2022.

have been further delayed this year, and the Japanese reactor does not even have a provisional startup date.

Construction Starts

- Construction started on 10 reactors in 2021, including six in China. The other four are implemented by Rosatom in India (2), in Turkey, and domestically. Two of the construction starts in China were also by Russia. In other words, of the global total of ten, six reactors were designed by Russian builders and four by the Chinese industry.
- Construction of three reactors started in the first half of 2022, all of them in China, two of which are of Russian design.
- Chinese and Russian government-owned or -controlled companies launched all of the 18 reactor constructions in the world over the 30-month period from the beginning of 2020 to mid-2022.

OPERATING AGE

- The average age (from grid connection) of operating nuclear power plants has been increasing since 1984 and stands at 31 years as of mid-2022.
- A total of 270 reactors, two-thirds of the world's operating fleet, have operated for 31 or more years, including 105—more than one in five—for at least 41 years.
- If all currently licensed lifetime extensions and license renewals are 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 decade to 2030, the net balance of operating reactors would turn negative as soon as 2024, and an additional 110 new reactors (83.5 GW)—one unit or 0.7 GW per month—would have to start up or restart to replace closures. This would mean the need to double the annual building rate of the past decade from six to twelve over the period to 2030.

FOCUS COUNTRIES

The following ten countries covered in depth in this report represent 30 percent of the nuclear countries, which operate two thirds of the global reactor fleet. Some key developments in 2021 and the first half of 2022:

China. Nuclear power generation increased by 11 percent and provided a stable 5 percent of total electricity generation. Meanwhile, wind energy output grew by 40 percent and solar by 25 percent. China failed its 2020-target for operating nuclear capacity and will miss its 2025-target of 70 GW by at least 9 GW.

Finland. The country's fifth reactor, the first European Pressurized Water Reactor (EPR) on the continent, under construction since 2005, finally started up in March 2022, 13 years later than scheduled. However, commissioning of the reactor has been hampered by a series of "unexpected" events. The Russian-designed Hanhikivi follow-up project was cancelled following the invasion of Ukraine.

France. Nuclear generation was up 7.5 percent following a 12-percent fall in 2020. In December 2021, stress corrosion cracking was first identified in safety injection systems of the largest and most recent reactors. Later the default was detected on other units.[12] The problem adds to extended outages due to ageing issues, backfitting, decennial inspections, and upgrading requested by the safety authorities. The subsequent decline in electricity generation is expected to lead in 2022 to an annual level last seen in 1990. The government has announced the renationalization of operator EDF, which faces potential bankruptcy.

Germany. Nuclear generation increased by 7.4 percent after a 14-percent drop in 2020. According to the legally binding phaseout schedule, three reactors were closed at the end of 2021, and the three remaining are scheduled to close by the end of 2022. Accordingly, the nuclear share declined to 5.6 percent in the first half of 2022. Triggered by the unfolding energy crisis, an unexpected controversy is underway about the potential stretching of the operation or a lifetime extension of the remaining three units. The government has proposed to put two of them into reserve status until the end of winter in mid-April 2023.

India. Nuclear generation has been slightly declining since 2019 and represented 3.2 percent of total electricity production. Eight reactors are listed as under construction, including four of Russian design. Meanwhile, both wind and solar continued growth and contributed more than 150 percent of nuclear power generation each.

Japan. One reactor was restarted from LTO since WNISR2021 (none was slated for closure). Nuclear generation increased by 42.2 percent but to provide 7.2 percent of the country's electricity. However, as of July 2022, only seven of ten licensed units generated power. In an unprecedented ruling, a Hokkaido District Court prohibited the restart of the only three reactors on the island due to concerns about spent fuel storage safety and protection levels against tsunamis.

South Korea. Nuclear generation slightly declined and provided 27.5 percent of electricity. The new administration clearly aims to shift nuclear policy away from a long-term phaseout (then rather a program limitation) and contemplates a stronger role for nuclear power further lowering the part of renewables. The country already has the lowest share of renewables in the power mix of any OECD member state.

Taiwan. Nuclear generation dropped by 11.6 percent following the closure of one reactor in mid-2021. The country follows a nuclear phaseout plan that will see the remaining three reactors closed by 2025. An attempt by the opposition and the nuclear lobby to overturn the phaseout policy by referendum and reactivate the construction of two reactors at Lungmen failed in December 2021. Renewables only contributed 4.2 percent of electricity, and, so far, only solar photovoltaics are developing rapidly with 1.9 GW in capacity added over the year.

United Kingdom. The nuclear program is declining faster than anticipated. Since June 2021, two reactors were closed, and the decision was taken to close two additional units that had not generated any power since 2018. Nuclear power contributed 14.8 percent to national power production, down from 26.9 percent in 1997. Renewables have seen a rise in two decades from 2.5 percent in 2001 to 39.6 percent in 2021, while coal declined in just the past decade

12 - As of 21 September 2022, 15 reactors are impacted by investigations or repairs.

from 39.2 percent to 2.6 percent. The construction project at Hinkley Point C continued to experience cost overruns and delays.

United States. Nuclear output peaked in 2019 and has dropped by a cumulated 3.9 percent by 2021; its share of commercial electricity generation declined to 18.9 percent, its lowest level since it peaked in 1995. The U.S. nuclear fleet is still the largest with 92 units and one of the oldest in the world with a mean age of 41.6 years. Cost estimates for the only two reactors under construction at the Vogtle site now exceed US$30 billion. Substantial new subsidy programs for uneconomic operating reactors and for new projects have been enacted on federal and state levels. Three major corruption and fraud investigations involving both new reactors and nuclear subsidies continued and involve politicians, utility-, and industry-executives.

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 stabilized.

Overview of Onsite and Offsite Challenges

Onsite Challenges

Spent Fuel Removal from the pool of Unit 3 was completed in February 2021. Preparatory work has only started on Units 1 and 2, with removal planned to begin in FY 2024 at the earliest.

Core Cooling. Water levels dropped in all three reactor pressure vessels after a 7.4 magnitude earthquake on 16 March 2022. Water injection rates have been increased again as a result.

Fuel Debris Removal, last planned to start with Unit 2 by 2021, had been delayed by "about one year due to the spread of COVID-19" and was delayed again following transmission loss of the camera mounted on a remotely operated vehicle. There is no new timeline for debris removal.

Contaminated Water Management. As water injection continues to cool the fuel debris, highly contaminated water runs out of the cracked containments into the basements where it mixes with water that has penetrated the basements from an underground river. Various measures have reduced the influx of water from up to 500 m^3/day to about 130 m^3/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 week.

About 1.3 million m^3 of treated water are stored in 1,020 tanks. As of 28 July 2022, capacity saturation had reached 96 percent, so the existing tanks would be full by summer or fall of 2023.

The safety authority agreed to operator TEPCO's plan to release the contaminated water into the ocean. Close to three quarters of the water would have to be treated again, then the water would be diluted by a factor of 100 (or more) before being released via a one-kilometer-long sub-seabed tunnel. The operation would 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 March 2022, about 32,400 residents of Fukushima Prefecture were still living as evacuees; the number decreased from a peak of close to 165,000 in May 2012. In June 2022, for the first time, the evacuation order was lifted for a district designated as "difficult-to-return" zone (an area with high levels of radiation). But only eight people from four households expressed an interest in returning to the district. For the first time, the evacuation order was also lifted for part of Okuma city that hosts the Fukushima plant. Only 3.6 percent of the residents returned. Rates of return have been much higher, 62–85 percent, in cases where evacuation orders have been lifted for entire municipal territories.

Food Contamination. According to official statistics, a total of 41,361 samples were analyzed in FY2021, of which 157 samples (30 more than a year earlier and 0.4 percent of total) exceeded the legal limits. As of February 2022, 14 countries—down from a peak of 54 countries—still had import restrictions for Japanese food items in place. In June 2022, the U.K. lifted its import restrictions.

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 August 2022, a total of about 13.3 million m^3 of contaminated soil had been transferred to such interim storage facilities. The government is legally responsible for the final disposal of the contaminated soil.

Health Issues and Legal Cases. In a first-of-a-kind procedure, in January 2022, a group of six men and women, diagnosed with thyroid cancer as children, filed a class action suit against TEPCO, seeking US$5.4 million in compensation. In March 2022, Japan's Supreme Court ordered TEPCO to pay compensation to 3,700 people impacted by the disaster but ruled out government responsibility for the catastrophe in a separate June-2022 judgement. In July 2022, the Tokyo District Court ordered four former executives of TEPCO to pay 13 trillion yen (US$95 billion) in damages to the company. The case was brought by TEPCO shareholders, and the ruling was the first time a court has found former executives responsible for the nuclear accidents.

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, their decommissioning is becoming a key challenge (note that the status of radioactive waste management is not part of this analysis).

- The number of closed power reactors exceeded 200 at the end of 2021, reaching 204 units with 97.4 GW of capacity as of mid-2022, eight more than one year earlier. 182 units are awaiting or are in various stages of decommissioning, five more than one year earlier.
- Only 22 units or 11 percent have been fully decommissioned, two more than a year earlier: 17 in the U.S., four in Germany[13], and one in Japan. Of these, only 10 or 5 percent of all closed reactors have been returned to greenfield sites for unrestricted use.
- The average duration of the decommissioning process is about 21 years, with a large range of 6–45 years (both extremes for reactors with very low power ratings of respectively 22 MW and 63 MW).
- Only three countries amongst the 23 with closed nuclear power reactors have completed the technical decommissioning process of at least one reactor: the United States (17 units), Germany (4), and Japan (1).
- The analysis of 11 major nuclear countries hosting 85 percent of all closed reactors shows that progress in decommissioning remains slow: of 146 units in various stages of advancement, 66 are in the "warm-up stage", 24 are in the "hot-zone stage", 11 are in the "ease-off stage", while 45 are in "long-term enclosure".
- None of the early nuclear states—U.K., France, Russia, and Canada—has fully decommissioned a single reactor yet.

POTENTIAL NEWCOMER COUNTRIES

Two potential newcomer countries had nuclear reactors under construction as of mid-2022: Bangladesh and Turkey. [Egypt started construction shortly after]. All of these projects are implemented by the Russian nuclear industry. The impact of sanctions and potential other geopolitical developments on the future of these projects is uncertain.

Other countries like Nigeria, Poland, or Saudi Arabia have more or less advanced plans, but so far neither selected a design nor assured a financing package. Several countries, including Indonesia, Jordan, Kazakhstan, Thailand, Uzbekistan, and Vietnam have suspended or cancelled earlier plans. Some key developments:

Bangladesh. Two reactors of Russian design have been under construction since 2017–2018. Both units are scheduled to start up in 2023 and 2024. There is widespread concern in the country about the safety and security of the plant.

Egypt. On 20 July 2022, despite the war in Ukraine, construction of the first, Russian designed, nuclear power plant was launched at the El-Dabaa site.

Nigeria. The country signed nuclear cooperation agreements with several countries and considers the option of developing up to 4 GW of nuclear capacity. Plans are vague and no design or provider has been chosen and no investment decision has been taken.

Poland. The country abandoned two reactors under construction following the Chernobyl accident in 1986. There have been repeated attempts to revive the program ever since. In

13 - Contrary to the categorization in previous WNISR editions that counted Gundremmingen-A to be fully decommissioned, the plant should rather be placed into the "Ease-Off-Stage" of decommissioning, as work is still ongoing.

December 2021, the site of Choczewo in Pomerania was chosen for a first plant. However, no design and no supplier have been selected, and no financing package has been assured.

Saudi Arabia. In 2013, a plan for the deployment of 18 GW of nuclear power was announced, with the first reactor to start operating in 2022. It did not happen. In May 2022, the government finally invited bids from China, France, Russia, and South Korea for the construction of two 1400 MW reactors.

Turkey. The Akkuyu site was selected in 1976 and several attempts to implement the project had failed until a 2010 agreement with Russia to build four reactors that were all to be in operation by 2019. After repeated delays, construction of these four units started between 2018 and 2022. Construction on Unit 4 started in July 2022, in the middle of the war in Ukraine. Turkish authorities hope to connect Unit 1 to the grid in 2023, to coincide with the 100th anniversary of the foundation of the Republic of Turkey.

SMALL MODULAR REACTORS (SMRs)

Following assessments of the development status and prospects of Small Modular Reactors (SMRs) in earlier WNISR editions, this year's update does not reveal any major advances but still increasing media attention and some additional public funding commitments. The country-by-country status:

Argentina. The CAREM-25 project has been under construction since 2014. Following numerous delays, the latest estimated date for startup is 2027. The lower end of cost estimates per installed kilowatt correspond to roughly twice the cost estimates for the most expensive Generation-III reactors.

Canada. There is continuous strong federal and provincial government support for the promotion of SMRs. While several grants to the value of tens of millions of dollars have been awarded to different design developers, the amounts remain small when compared to what would be required to advance one of these designs to the point of being licensed for construction. No design has yet been transmitted to the safety authority for review, leave alone for certification.

China. Construction on two high-temperature reactor modules started in 2012. The first module was connected to the grid for a few days in December 2021, almost five years behind schedule. Reportedly, neither unit has generated power since. The reasons are unknown. Construction started on a second design, the ACP100 or Linglong One, in July 2021, six years later than planned. It is scheduled to be completed by early 2026.

France. In February 2022, President Macron announced a €500 million contribution (US$559 million) until 2030 to the financing of the development of the Nuward SMR design. However, EDF made it clear that the project is not high amongst its priorities.

India. An Advanced Heavy Water Reactor (AHWR) design has been under development since the 1990s, but its construction has been continuously delayed. Earlier in 2022, the government announced that a "Pre-Licensing Design Safety appraisal of the reactor has been completed".

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. A second SMR project, a lead-cooled fast reactor design, was launched in June 2021.

South Korea. The System-Integrated Modular Advanced Reactor (SMART) has been under development since 1997. In 2012, the design received approval by the safety authority, but there have been no orders. Reportedly, several other designs are in very early stages of development.

United Kingdom. Since 2014, Rolls Royce has been developing the "UK SMR", a 470 MW reactor (exceeding the size-limit of 300 MW for the usual SMR definition). In November 2021, Rolls Royce announced it had received US$281 million in government funding and US$261 million from private sources (including company funding), far short of its earlier calls for US$2.8 billion in support. In March 2022, the regulator accepted the design for a Generic Design Assessment (GDA).

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 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 Utah, leaving the 6-module 462 MW project with subscriptions amounting to just 101 MW. Cost estimates (including financing) have ballooned to US$5.3 billion.

NUCLEAR POWER AND WAR

Russia's invasion of Ukraine has led to several unprecedented events including the operation of commercial nuclear power plants during a full-scale war, shelling of commercial reactor sites, the occupation by enemy forces of nuclear facilities, and the operation of reactors under physical threat. No nuclear power plant in the world has been designed to operate under those conditions.

Vulnerabilities of Reactors and Spent Fuel Pools

- A nuclear power plant depends on continuously functioning cooling systems to evacuate decay heat from reactor cores and spent fuel pools, even when the reactor is shut down.
- Immediately after shutdown, a reactor core still generates about 7 percent of the nominal thermal power. Decay heat decreases with time, first rapidly, then slowly. After one day residual heat is at about 0.5 percent (considerable 15 MWth in the case of a 1,000 MWe reactor) and still half of that after ten days.
- After the service life, the spent fuel is unloaded from the reactor core and placed in a pool filled with water. The residual heat must be permanently evacuated from the pool in order to prevent the fuel from overheating.

- Failure to evacuate residual decay heat will lead to core meltdown or spent fuel fire with potentially large releases of radioactivity.
- Effective cooling chains—usually three cooling circuits linked together via heat exchangers and a final heat sink like a river, a lake, or the ocean—must be available at all times to evacuate residual heat from the reactor core and from the spent fuel pool.

Nuclear Power Plants and Spent Fuel Storage in War

Power Supply in War Times

- Some countries heavily rely on nuclear power. In 2021, eight countries generated over one third of their electricity from nuclear plants (Ukraine 55 percent). The higher the nuclear share, the more difficult to shut down all reactors as a precautionary measure in case of war.
- The attacker might want to disrupt the power supply of the attacked country in the short term but might also wish to maintain power supply in the longer term in case the objective is the occupation of attacked territories. In any case, nuclear power plants are strategic sites.

Nuclear Power Plants and Nuclear Weapons

- Nuclear explosive devices can contain plutonium and/or highly enriched uranium as fissile material.
- Highly enriched uranium (HEU) is not used in common commercial nuclear power reactors (although some research reactors, naval applications, and fast reactors run on HEU).
- Every nuclear power plant generates weapons usable plutonium in its fuel during normal operation. The extraction of plutonium from highly radioactive irradiated fuel requires remote-handling equipment (a large hot cell or a reprocessing plant).
- An attacker can either suspect or insinuate that the designated enemy has used or is planning to use its power reactors to produce plutonium for a weapons program.

Fear of an Accident as Political Pressure Tool

- Nuclear power plants can release large quantities of radioactive substances in case of accident. Wartime destruction would lead to similar consequences.
- The attacker can use the threat of destruction as blackmail as the country hosting the nuclear facilities has an obvious interest in preserving public health and the environment.

Multiple Indirect Threats to Nuclear Safety in Wartime Situations

Regardless of whether there is a military rationale to occupy, recapture, or destroy in a scorched-earth mode a nuclear power plant site, there can be multiple unintended causes of impact on nuclear safety.

- Accidental hits due to limited accuracy of weapon systems.
- Collateral damage in the course of a military campaign.
- Limited knowledge of combatants of safety relevance of parts of a nuclear plant.
- In a life-or-death combat situation, nuclear safety will likely not be a priority.
- The power plant site can be used as a shield, thus becoming an impregnable fortress.

Specific Vulnerabilities of Nuclear Power Plants

Nuclear power plants are complex industrial facilities. Their safe operation depends on a stable technical, human, regulatory, political, and economic environment. Previous research on nuclear safety have taken these stable conditions for granted.

The consequences of system failures are nevertheless the same, whether they are triggered by accident or by the effects of war.

- Direct destruction of safety-relevant parts can be caused by military munitions on purpose or by mistake.
- Some important safety systems are located in the reactor buildings that vary greatly in design. While many are robust buildings, only few are truly bunkered.
- Many important safety systems are located in other traditional industrial buildings including parts of the cooling chains, large parts of the power supply, transformers, diesel generators for emergency power, generator fuel, switchgear, and the control room.

Power Supply

- A stable connection to the power grid is the most important requirement for electricity supply.
- Electricity is required at all times to operate large pumps in the various cooling chains.
- In the case of grid loss, emergency generators can supply the minimum required to maintain the cooling systems operational for a short time, but they are not designed for continuous long-term operation.
- A shutdown nuclear power reactor cannot be restarted from diesel generators and needs the grid connection to operate again.
- In case of multi-unit sites, one operating reactor can also supply its own and the other units' basic needs for electricity (island mode). Switch to island mode frequently fails and is highly unstable.

Cooling Water Supply and Other Important Infrastructure

- An operational cooling capacity is as vital for nuclear safety as a reliable power supply.
- Interruption of pipelines, destruction of the links to the final heat sink, or pump inlets blocked by debris would jeopardize the cooling capacity.

- Free road access is essential for rotating shifts, delivery of spare parts, outside personnel, and emergency services like fire departments.

Skilled Operating Staff

- Reactor operators are trained for a specific individual plant. They cannot be simply replaced by operators from other plants, including those from an attacker country.
- Under war conditions, staff are unsure whether they can leave the plant at the end of their shift, uncertainties that heighten their stress level.
- Operating a nuclear facility at gun point could easily lead to considering even standard safety procedures as secondary.
- Staff will likely be deprived of their usual communication tools like their cell phones, restricting their ability to exchange with colleagues, supervisors, and regulators. Uncertainty about the well-being of family and friends in the middle of an active war zone further increases the stress level.

Maintenance

- Regular maintenance is indispensable, including the delivery and installation of replacement parts, some of which might have to be ordered from foreign suppliers.
- Annual outages usually involve a large number of subcontractors. These companies might not want or be able to send their employees into a war zone or into an occupied nuclear power plant.

Inspection

- Inspections by the state regulator or other third parties are an integral part of the safety approach. They will likely not be carried out under warlike conditions.
- International organizations like the IAEA have certain inspection rights under international law. These will likely not be implemented, at least not under usual conditions.

Specific Vulnerabilities of Spent Fuel Storage Facilities

- All nuclear power plants have spent fuel storage pools, some are in the reactor buildings, some are in separate, considerably less robust buildings.
- While spent fuel pools are better protected inside the containment, there is a possibility that in case of a severe accident on the reactor, the pool will be impacted as well.
- Spent fuel pools, especially centralized pools that serve several reactors, contain the equivalent of several, up to several dozen reactor cores and thus cumulate very large radioactivity inventories.
- After several years of cooling, spent fuel can be moved to dry storage casks. The residual heat is removed by the air flow and no active cooling system is needed.
- Pool destruction or disruption of power and cooling water supply:

- The cooling chain of the pool could be interrupted, which would lead to the progressive evaporation of the cooling water and uncover the fuel within days or weeks.
- If the pool itself is damaged or destroyed the water would be lost. The fuel would likely self-ignite and release a large share of its radioactive inventory.
- In case of a power cut, the cooling chain would become dysfunctional. The grace time would be significantly longer compared to the reactor core cooling but could eventually lead to fuel destruction.

POSSIBLE RELEASE MECHANISMS AND SCENARIOS

Nuclear Power Plant

- → The interruption of core cooling at an operating nuclear reactor would lead to a core-melt accident within less than one hour to several hours. A meltdown would also occur at a shutdown reactor with a delay depending on various parameters, especially the time elapsed since shutdown.
- → During a core meltdown, free hydrogen is formed that can explode (see Fukushima events).
- → If the containment is breached, e.g. by a military strike in a wartime situation, a meltdown would release a significant fraction of the radioactive inventory into the environment.

Spent Fuel Storage

- → The interruption of cooling spent fuel in a pool leads to progressive evaporation until the fuel elements are partly or wholly uncovered. They then heat up until the cladding is destroyed and release radioactivity into the environment. At higher temperatures, explosive hydrogen can also be formed. When strongly heated cladding material is exposed to air, it can also catch fire. Under this scenario a very large fraction of the radioactive inventory would be released to the environment and lead to widespread contamination.
- → In the case of a dry storage facility, only the destruction of the container integrity would lead to war-induced radioactivity releases. Most cask-destruction scenarios would lead to geographically limited radiation effects, except for a munition-triggered spent fuel fire.

TIMELINE: WAR IN UKRAINE

- → It should be noted that the Nuclear Power and War chapter has been drafted in May 2022. It is striking to what extent, many of the theoretical assumptions have—reportedly—turned into reality in the following months of the war in Ukraine.
- → In a war situation, it is particularly difficult to verify whether certain reports cover indisputable facts, are exaggerated, or false. We have therefore refrained from attempting an objective account of what is happening in Ukraine with and at nuclear facilities.
- → Nevertheless, some insight into the developments should be provided. Therefore, we have compiled a timeline from 24 February to 13 September 2022 based exclusively on two sources: the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) and the

International Atomic Energy Agency (IAEA). Neither are neutral in this conflict, a situation requiring appropriate caution.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

The year since the publication of WNISR2021 has been seminal for climate change and energy security, nuclear power, and renewable energy, with climate change high on the political agenda and an energy crisis in the making in the second half of 2021. Obviously, 2022 has been dominated by the events in Ukraine which had significant effects on energy-policy decisions for the short and medium term.

Investment. In 2021, total investment in non-hydro renewable electricity capacity reached a record US$366 billion, 15 times the reported global investment decisions for the construction of nuclear power plants that have nevertheless increased over the previous year by about one third to US$24 billion for 8.8 GW. Investment in solar surged by 37 percent to reach US$204 billion and investments in wind power plants increased by 2.8 percent to US$146 billion. Individually, solar investments total 8.5 times and wind six times nuclear power investment decisions.

Costs. Levelized Cost of Energy (LCOE) analysis by U.S. bank Lazard shows that between 2009 and 2021, utility-scale solar costs came down 90 percent and wind 72 percent, while new nuclear costs increased by 36 percent. The gap continues to widen. Estimates by the International Renewable Energy Agency (IRENA) has seen the LCOE for wind drop by 15 percent and solar by 13 percent between 2020 and 2021 alone. IRENA also calculated that 800 GW of existing coal-fired capacity in the world have higher operating costs than new utility-scale solar photovoltaics (PV) and new onshore wind.

Installed Capacity. In 2021, wind added 92 GW of new capacity and solar PV capacity grew by 138 GW, largely contributing to the new global record of 257 GW of non-hydro renewables added to the world's power grids. These numbers compare with a net *decrease* of 0.4 GW in operating nuclear power capacity.

Electricity Generation. In 2021, the annual global growth rates for the generation from wind power were 17.0 percent (11.9 percent in 2020), 22.3 percent (20.9 percent in 2020) for solar PV, and 3.9 percent (-4 percent in 2020) for nuclear power.

Share in Power Mix. In 2021, wind and solar alone reached a 10.2 percent share of power generation, the first time, they provided more than 10 percent of global power and surpassed the contribution of nuclear energy that fell to 9.8 percent. The nuclear share is below 10 percent for the first time in four decades. Non-hydro electricity generation outperformed nuclear power production by 30.6 percent. The gap widens.

China. In 2021, renewable-energy-based gross power generation grew faster than any other energy sources, with wind producing 656 TWh, solar, 327 TWh, compared to 407.5 TWh (383 TWh net) for nuclear and 1,300 TWh for hydro. Thus, wind turbines generated 71 percent more power than nuclear reactors and solar remained just 15 percent short of the nuclear output.

European Union. In 2021, renewable electricity generation in the E.U. reached a new record of 1,068 TWh—a 9 percent (+88 TWh) jump compared to 2019—and accounted for 37 percent of the E.U.'s electricity production, up from 34 percent in 2019. In comparison, nuclear power produced 733 TWh gross (699 TWh net), around 7 percent more than the previous year, but about 4 percent lower (-32 TWh) than in 2019. Nuclear accounted for 26 percent of E.U. electricity production in 2021.

India. Solar power capacity reached 49.7 GW at the end of 2021 overtaking for the first time the installed capacity of wind with 40.1 GW. Wind has outpaced nuclear in power generation since 2016. Solar passed nuclear generation in 2018 and wind power output in 2021. Wind and solar with each generating 68 TWh together produced 3.4 times more power than nuclear plants. Nuclear electricity production has been declining slightly since 2019.

United States. In 2021, installed wind capacity increased by a record 17 GW, solar added 15.5 GW. Wind power generation increased by 13 percent and solar output by 25 percent while nuclear energy generation dropped to the lowest level since 2012. Renewables provided 14 percent of commercial power while nuclear still contributed just under 20 percent.

INTRODUCTION

The year that passed since the publication of WNISR2021 has seen dramatic geopolitical changes in the world with energy issues playing a key role. Low natural gas supply and storage levels in the second half of 2021, and the war in Ukraine and its consequences in 2022 have laid bare Europe's dependencies on fossil fuels from Russia.

Despite the world's media focused on Russia and on energy supplies, there has been little attention given to the extent of interdependencies with Russia's nuclear sector. About half of the natural uranium imported by the European Union (EU) in 2020 was purchased from Russia, and Kazakhstan and Uzbekistan, two Former Soviet Union countries (FSU). Five days after the Russian invasion of Ukraine began, and one day after the European Union closed its airspace to all Russian aircrafts, the Slovakian Government provided a special permission to a Russian plane to fly fresh nuclear fuel assemblies into the country. Slovakia is operating six Russian designed VVER reactors that, in 2021, generated more than half of its electricity. Two additional units, under construction at Mochovce since 1985, are expected to start up soon, with Russian fuel.

The shipment to Slovakia was not the only one to get exceptional flight permission for Russian nuclear fuel. Besides Slovakia, Bulgaria, the Czech Republic, Finland, and Hungary operate VVERs and depend on Russian fuel. Westinghouse, the only other manufacturer, has so far supplied VVER fuel mainly to Ukraine. Even though Ukraine started to get off Russian fuel several years ago, it has converted only about half of its 15 reactors to the alternative fuel. Some other European VVER operators have shown interest in the option in the past and that interest has obviously grown in the past six months.

There are many other services provided by the Russian nuclear industry, which also carries out joint activities with several EU entities. Rosatom has been cooperating with French utility EDF for 30 years in many areas. In 2009, Rosatom purchased the German former nuclear fuel manufacturing company Nukem, now specializing in decommissioning. In December 2021, Rosatom and EDF subsidiary Framatome signed a "long-term cooperation agreement" (see press release hereunder), and in early 2022, Rosatom subsidiary TVEL was about to take a stake in Framatome's fuel manufacturing plant in Lingen, Germany. Rosatom was also to acquire a 20-percent share in Arabelle-turbine manufacturer GEAST. These turbines produce electricity for European Pressurized Water Reactors (EPR) and Rosatom's VVER plants. With Russia dominating the narrow international nuclear newbuild market, sanctions against Rosatom would deprive EDF's subsidiary GEAST from its main customer.

The European Parliament has explicitly called for the inclusion of the nuclear sector in sanctions against Russia. Do these commercial interdependencies explain why the call was not followed-up?

The Russian military occupation of the two nuclear sites, Chernobyl and Zaporizhzhia, and the involvement of Rosatom staff in the forced operation of the facilities by Ukrainian personnel raises questions about the relationship of commercial companies, whether public or private, with the Russian state-owned company.

IIt also raises questions about the role of the International Atomic Energy Agency (IAEA). The Agency's Director General Rafael Mariano Grossi visited the Ukrainian nuclear sites and confirmed Rosatom's presence in Zaporizhizha. While Grossi is lobbying for a security zone around nuclear facilities, Mikhail Chudakov, former longtime official of Rosatom companies, remains his Deputy Director General and Head of the IAEA's Department of Nuclear Energy.

The IAEA General Assembly started on 26 September 2022, while this is being written. It will be an important challenge to clarify what the basic conditions for technical assistance are and will be in the future. Today, Russia is the country that implements the most new-build projects around the world, many, if not a majority, with the assistance of the IAEA. It is of utmost importance for the IAEA to clarify the conditions under which Russia, state-owned Rosatom, and its many subsidiaries can be seen as a responsible partner for nuclear cooperation in the future.

The issue of shared industrial interests between Russian and non-Russian companies would have merited a focus chapter in WNISR2022. It did not happen. WNISR2022 is nevertheless covering a large range of issues including, for the first time, the implications and risks of operating nuclear power plants in wartimes.

Other developments occurred during the past year that would have merited in-depth coverage in WNISR2022 but proved impossible within the limited capacity of the team. These include:

- The European Parliament's adoption of the Commission's proposed Delegated Act that includes certain nuclear and gas activities under the EU Taxonomy of environmentally sustainable economic activities. The regulation will enter into force on 1 January 2023.
- An expansion of our earlier analysis of the COVID-19 pandemic's serious impacts on the operation, construction, inspection, and control of nuclear power plants.

Because the situation rapidly changed in many countries as a consequence of the war in Ukraine—e.g. the controversy about potential lifetime extensions in Germany—we paused WNISR's standard editorial practice of limiting content to occurrences before 1 July of the year of publication and updated some chapters well into September 2022.

The winter 2022/2023 might turn into a tough test of the European energy system's resilience. Some countries rely heavily on natural gas for heating homes and creating industrial process heat (e.g. Germany), while others rely on nuclear energy for electricity generation (e.g. France). Both sets of countries encounter serious difficulties. While Germany is struggling to compensate for the lack of Russian gas, France is affected by a large fraction of its reactors not operating due to multiple causes. Of any EU-country, France has by far the highest thermal sensitivity in the electricity system. If the thermometer drops by 1°C, the power generating capacity needs climb by 2.4 gigawatt—the equivalent of two large reactors—to cover additional electric space heating needs. Another significant parameter will be the extent to which the wind blows over the European continent. The climate might provide the ultimate system test.

Framatome Press Release, 2 December 2021

framatome

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PRESS RELEASE

Framatome and Rosatom sign long-term cooperation agreement

December, 02 2021 | 1 min | Partager

Categories: Fuel, instrumentation & control

December 2, 2021 - Framatome and Rosatom recently signed a new Strategic Cooperation Agreement further expanding the companies' efforts to develop fuel fabrication and instrumentation and control (I&C) technologies. Rosatom Director General Alexey Likhachev, and Bernard Fontana, CEO of Framatome signed the agreement during the World Nuclear Exhibition held in Paris.

Rosatom Director General Alexey Likhachev, and Bernard Fontana, CEO of Framatome shake hands to close agreement.

"By working closely with our industrial partner Rosatom, we strengthen our contributions for safe and reliable generation of clean energy generated by our customers nuclear operating plants," said Bernard Fontana. "Together, we build on our expertise for maintaining operations for the existing nuclear fleet and preparing for the next generation of nuclear energy."

"Together with Framatome, we are creating a solid foundation for developing high-quality nuclear energy solutions within the scope of current and future areas for collaboration," said Alexey Likhachev. "Today, the world has finally recognized that it is impossible to achieve carbon neutrality without nuclear generation. Therefore, we must hasten our collective efforts towards achieving global decarbonization goals."

The new agreement expands the companies' existing relationship, established through a 2017 memorandum of understanding, creating a framework for joint work in new areas.

GENERAL OVERVIEW WORLDWIDE

PRODUCTION AND 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 U.K., and the U.S.[14] 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".[15]

As of the end of 2021, 33 countries operated nuclear power programs in the world. 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.
- Five countries (China, Romania, Iran, United Arab Emirates, and Belarus) started up power reactors for the first time over the 30-year period 1991–2020 (none in 2021).
- 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.
- Three countries (Italy, Kazakhstan, Lithuania) abandoned their nuclear programs.
- Fifteen of the current 33 nuclear countries have active reactor construction programs.
- Eighteen countries are not constructing any reactors currently; of these, eight countries have either nuclear phase-out, no-new-build or no-program-extension policies in place. Some of these policies are currently being reviewed.

In 2021, the world nuclear fleet generated 2,653 net terawatt-hours (TWh or billion kilowatt-hours) of electricity[16], (see Figure 2) After a decline in 2020, nuclear production increased by

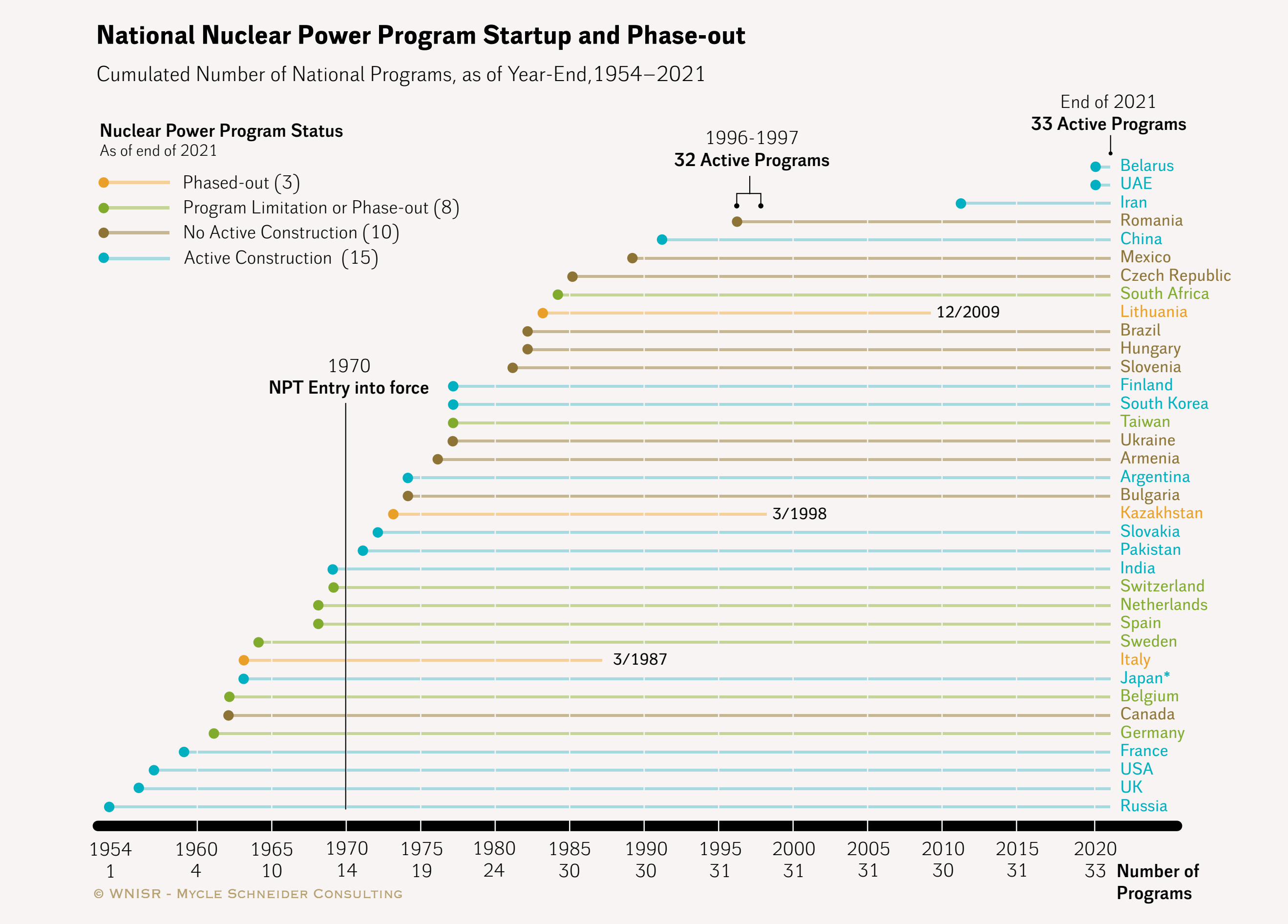
14 - Four additional countries have since acquired explosive nuclear devices (Israel, India, North Korea, and Pakistan). South Africa developed and manufactured nuclear weapons but has dismantled its program. For an overview see IPFM, "Global Fissile Material Report 2022—Fifty Years of the Nuclear Non-Proliferation 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.

15 - 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.

16 - 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 https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

3.9 percent in 2021, but stayed just below the 2019 level. China, with an 11.3 percent increase, produced more nuclear electricity than France for the second year in a row, and remains in second place—behind the United States—for the top nuclear power generators. Outside of China, nuclear production increased 2.8 percent to a similar level as in 2017.

Figure 1 · National Nuclear Power Program Development



Sources: Compiled by WNISR, with IAEA-PRIS, 2022

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.

Nuclear energy's share of global commercial gross electricity generation in 2021 was 9.8 percent—the lowest value in four decades—and over 40 percent below the peak of 17.5 percent in 1996.[17]

Nuclear's main competitors, non-hydro renewables, grew their output by 16 percent and their share in global power generation increased by 1.1 percentage points to 12.8 percent.[18]

17 - BP, "Statistical Review of World Energy 2022 – 71th edition", June 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 28 June 2022.

18 - Ibidem.

In 2020, in a global economic environment depressed by the COVID-19 pandemic, fossil fuel consumption slumped: oil by 9.7 percent, coal by 4.2 percent, and natural gas by 2.3 percent. In 2021, in the power sector, 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.

Nuclear commercial primary energy consumption increased by 3.6 percent while its share in global consumption remained stable at 4.3 percent; it has been around this level since 2014. In the European Union (EU) nuclear primary energy consumption increased by 6.7 percent, mainly due to generation increases in Belgium and France compared to 2020.

Non-hydro renewables, including mainly solar, wind and biofuels, continued their growth, with an unprecedented 14.7 percent increase, to reach a share of 6.7 percent in primary energy. While the share of non-hydro renewables is now 1.6 times the nuclear share, both figures illustrate how modest the current contribution of both technologies remain in the global context.[19]

In 2021, there were six countries that increased the share of nuclear in their respective electricity mix (including the two newcomer countries Belarus and United Arab Emirates) — versus eight in 2020— while nine decreased, and 18 remained at a constant level (change of less than 1 percentage point). Besides the two newcomer countries, six countries (Argentina, Belgium, China, Czech Republic, Pakistan, Russia) achieved their largest ever nuclear production. China, Pakistan, and the United Arab Emirates (UAE) started up new reactors during the year, while the others either profited from startups in the previous year, returns from long upgrading, or backfitting outages.

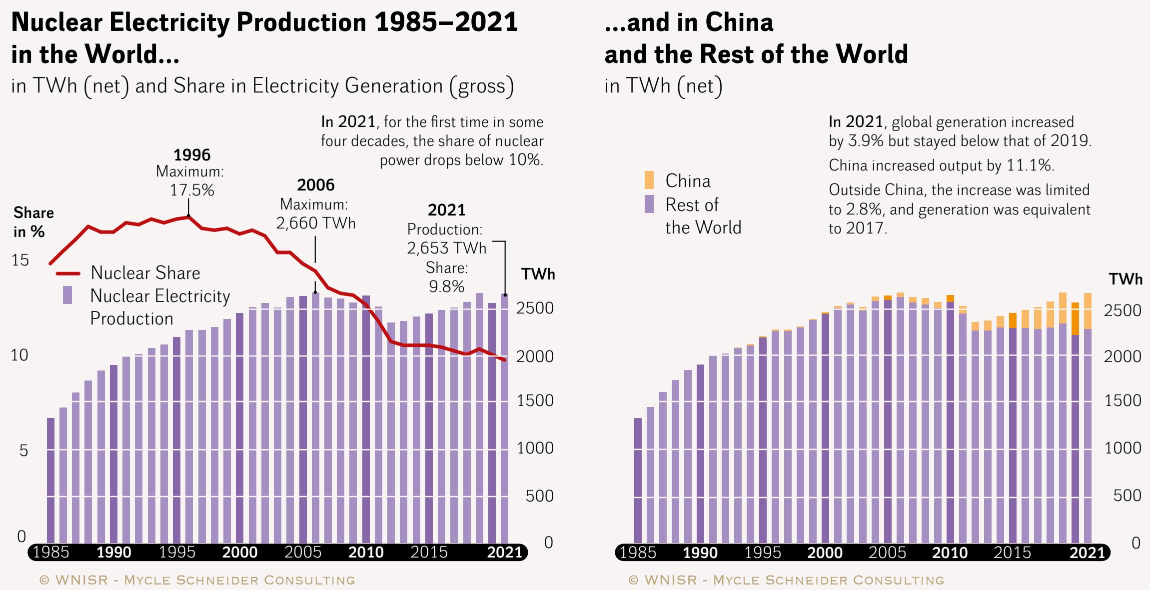
The following noteworthy developments for the year 2021 illustrate the volatile operational situation of the individual national reactor fleets (see country-specific sections for details):

- **Belgium** had an exceptional 2021 after years of struggling with technical issues greatly varying nuclear power generation. Output increased by 46 percent in the past year, following a plunge of 21 percent in 2020, a 52-percent increase in 2019, and a 32-percent drop in 2018.
- **China** started up three units versus two in 2020, just as in 2019, with nuclear generation increasing 11.2 percent, despite the full outage of the Taishan-1 EPR since July 2021.
- **France**'s nuclear generation increased by 7.3 percent following a 12-percent drop in 2020 but remained below 400 TWh for the sixth year in a row. The outlook for 2022 is dire because numerous reactors have been shut down for various technical reasons.
- **Germany** generated 7.4 percent more nuclear electricity than in 2020. However, three reactors were closed at the end of 2021.
- **Japan** had restarted nine reactors after all of them were down in 2014. But after a progressive increase in output, nuclear generation plunged in 2020 by over 34 percent. In 2021, nuclear production increased again by a remarkable 42.2 percent.
- **South Africa** has a highly volatile nuclear generation pattern. In 2021, the country generated 5 percent more nuclear power than in 2020. In previous years, production declined by 15 percent in 2020, increased by 28 percent in 2019, and dropped by 30 percent in 2018.

19 - Ibidem.

- **Sweden's** nuclear output increased by 8.6 percent following a 26.5 percent drop in 2020, partly due to the closure of one reactor (Ringhals-2).
- The **U.K.** nuclear generation has been decreasing steadily since 2016, by another 8.5 percent in 2021, partly due to the closure of three reactors. Since 2016, annual production has dropped by 36 percent. The trend will continue as three more reactors have been closed in 2022 (as of the end of August).
- In the **U.S.**, following the all-time high in 2019, in 2020, nuclear electricity generation dropped (by 2.4 percent) below the 800 TWh mark for the first time since 2015. Five reactors were closed 2019–2021 and, as stated in WNISR2021, it is possible that the country has seen "peak nuclear" and will not get back to earlier production levels.

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



Sources: WNISR, with BP, IAEA-PRIS, 2022[20]

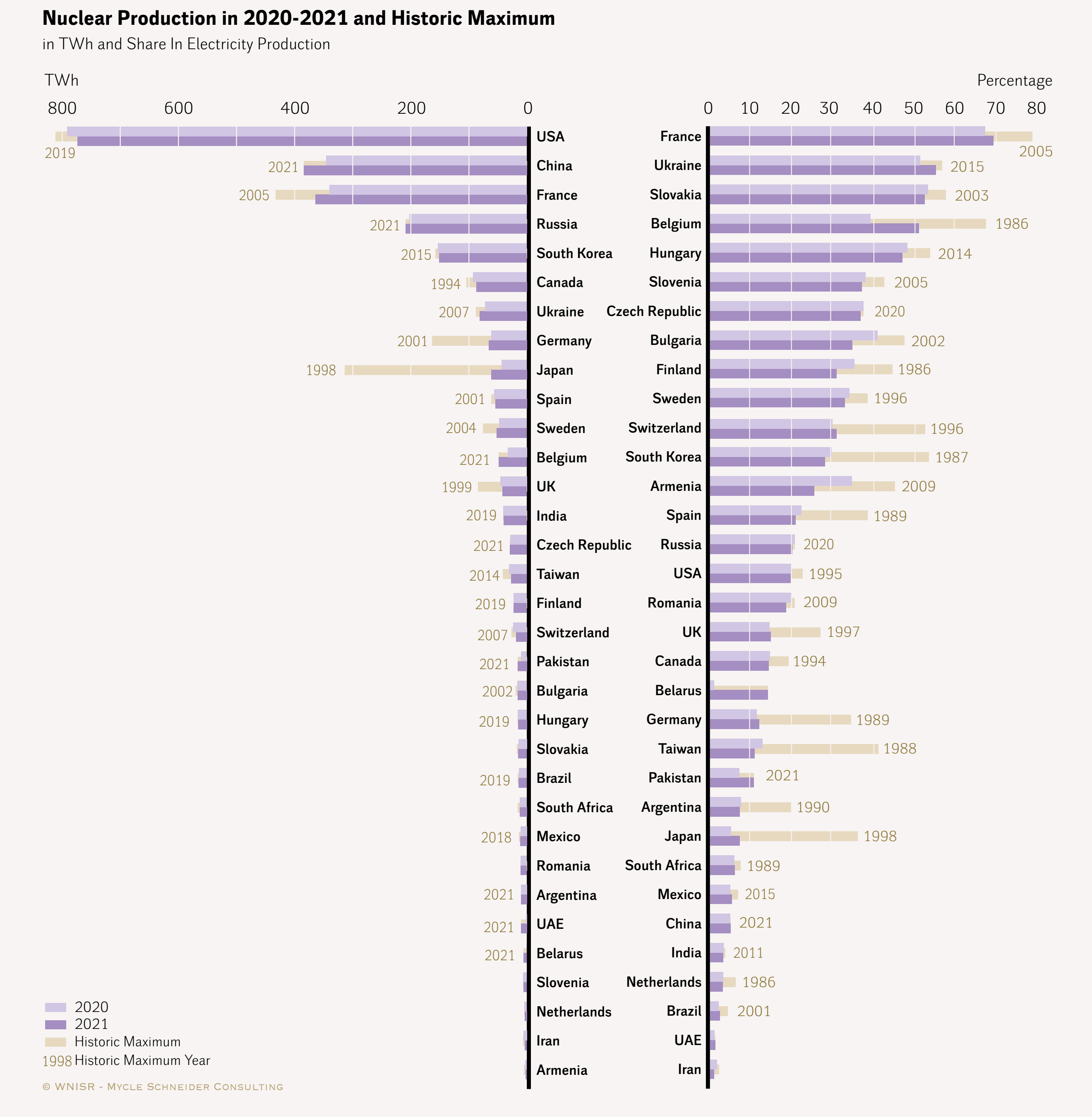
Similar to previous years, in 2021, the "big five" nuclear generating countries—the U.S., China, France, Russia, and South Korea, in that order—generated 71 percent of all nuclear electricity in the world (see Figure 3, left side).

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 2021, the top three countries, the U.S., China, and France, accounted for 57 percent of global nuclear production, underscoring the concentration of nuclear power generation in a very small number of countries.

20 - WNISR for World Nuclear Industry Status Report, BP stands for BP plc.

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



Sources: IAEA-PRIS, and national sources for France and Switzerland, compiled by WNISR, 2022

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

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 1990, in other words, almost half of the nuclear countries had seen the peak before the turn of the century.

Besides the two newcomers which started reactors in 2020 and 2021, only two countries, Pakistan and China reached new historic peak shares of nuclear in their respective power mix. China saw a negligible increase of 0.1 percentage points to 5 percent and Pakistan's nuclear share advanced by 3.5 percentage points to 10.6 percent.

OPERATION, POWER GENERATION, AGE DISTRIBUTION

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 in that year. The second reached a historic maximum in 1984 and 1985, just before the Chernobyl accident, 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[21] outweighed the number of startups.

The 1992–2001 decade globally produced twice as many startups than closures (51/25), while in the decade 2002–2011, startups amounted to less than two third of the closures (36/61). Furthermore, it took the whole decade 2000–2009 to connect as many units (33) as in a single year in the middle of the 1980s (see Figure 4).

In the past decade 2012–2021, 62 reactors—of which 37 (60 percent) in China—were started-up, and 44 were closed.

Over the two decades 2002–2021, there were 98 startups and 105 closures. Of these, 50 startups were in China which did not close down any reactors. As a result, outside China, there has been a drastic net decline by 57 units over the same period (see Figure 5). As larger units were started up (totaling 88 GW) than closed (totaling 66 GW) the net nuclear capacity added worldwide over the 20-year period was 22 GW. However, since China alone added 47.5 GW, the net capacity outside China declined by over 25 GW.

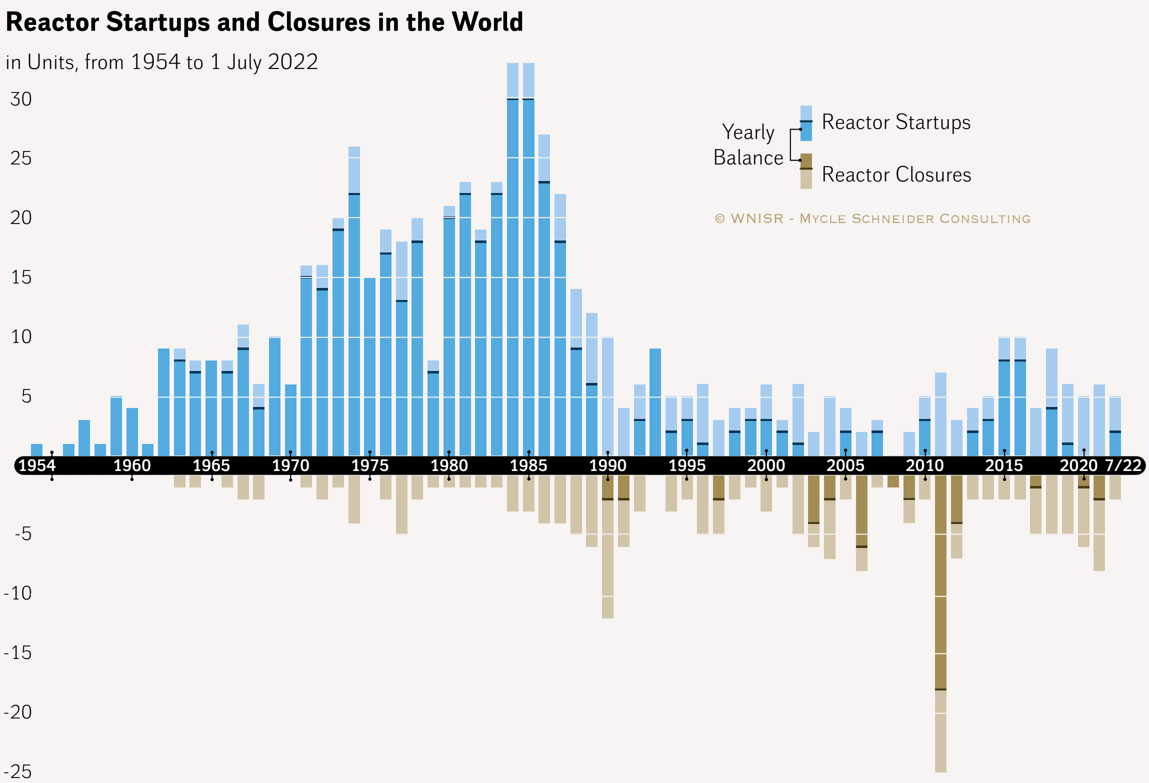
After the startup of 10 reactors in each of the years 2015 and 2016, only four units started up in 2017, of which three in China and one in Pakistan (built by Chinese companies). In 2018, nine reactors generated power for the first time, of which seven in China and two in Russia. In 2019, six units were connected to the grid, of which three in Russia, two in China, and one in South Korea, while five units were closed, of which two in the U.S., and one each in Germany, Sweden and Switzerland.

In 2020, five units were connected to the grid, two in China and one each in Belarus, Russia and the United Arab Emirates (UAE). During the year, six units were closed including two each in France and the U.S. and one each in Russia and Sweden. 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, including three in Germany and one each in Pakistan, Russia, Taiwan, U.K., and U.S. Two additional closures in the U.K. were announced during the year but they had not generated any power since 2018.

21 - With WNISR2019 we have introduced "closure" as general term for permanent shutdown, in order to avoid confusion with the use of "shutdown" for provisional grid disconnections for maintenance, refueling, upgrading or due to incidents. 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.

Five new units were connected to the world's power grids in the first half of 2022, including two in China, while two reactors were closed, one each in the U.S. and the U.K. (See Figure 5).

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



Sources: WNISR, with IAEA-PRIS, 2022

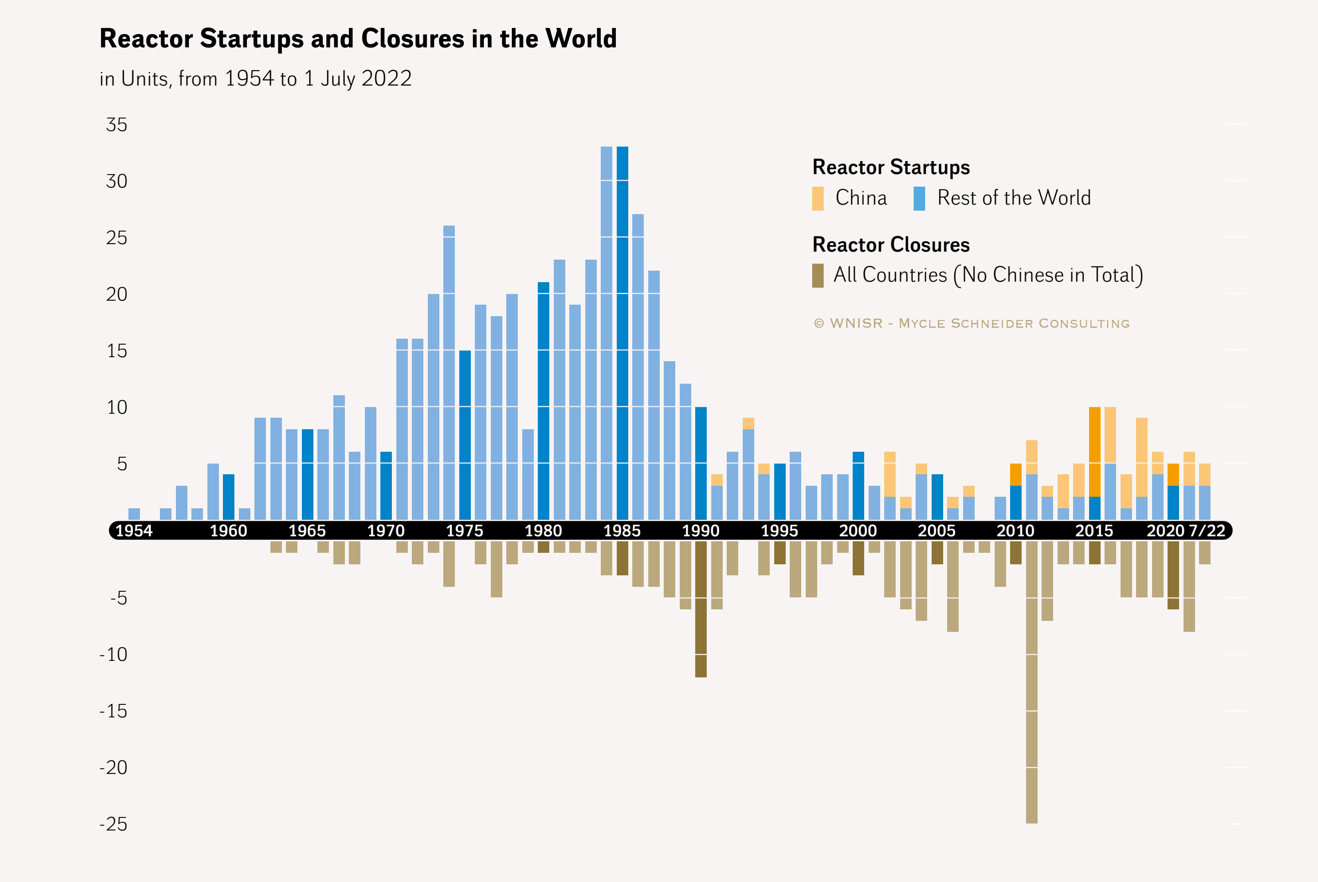
Notes:
As of 2019, WNISR is using the term "Closed" instead of "Permanent Shutdown" for reactors that have ceased power production, as WNISR considers the reactors closed as of the date of their last production. Although this definition is not new, it had not been applied to all reactors or fully reflected in the WNISR database; this applies to known/referenced examples like Superphénix in France, which had not produced in the two years before it was officially closed or the Italian reactors that were de facto closed prior to the referendum in 1987, or some other cases. Those changes obviously affect many of the Figures relating to the world nuclear reactor fleet (Startup and Closures, Evolution of world fleet, age of closed reactors, amongst others.)

As of 1 July 2022, a total of 411 nuclear reactors were operating in 33 countries, down four units from the situation in mid-2021.[22] The current world fleet has a total nominal electric net capacity of 369 GW (no change since WNISR2021), representing a peak just above the former record of 367 GW 2006. As the annual statistics always reflect the status at year-end, the situation might change again by the end of 2022.

The number of operating reactors remains by seven below the figure reached already in 1989 and by 27 below the 2002 peak (see Figure 6).

22 - +7 startups +1 restart –4 new LTO –8 closures.

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



Sources: WNISR, with IAEA-PRIS, 2022

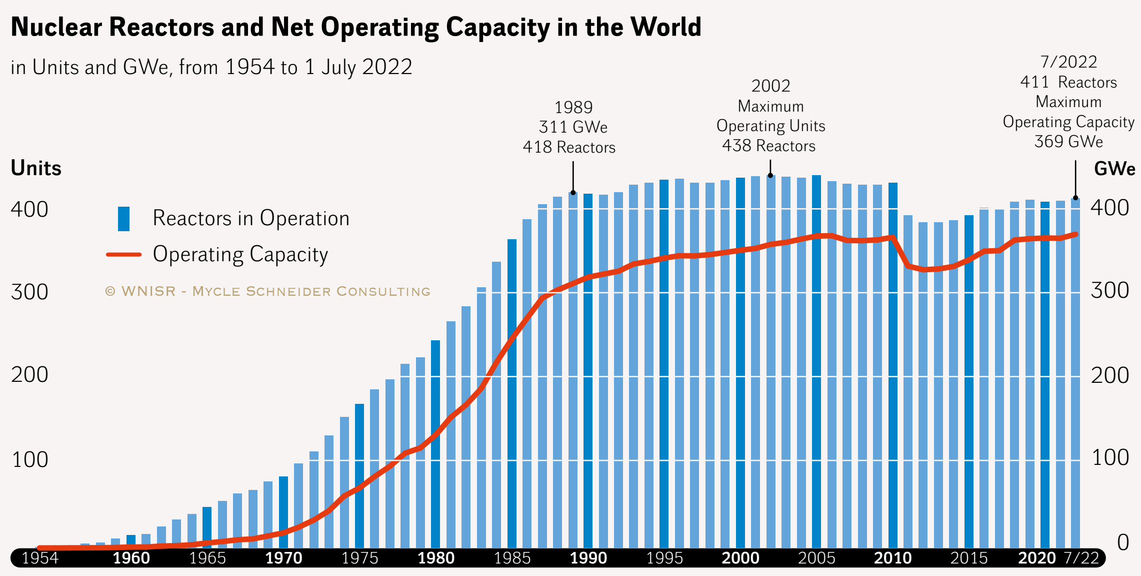
For many years, the net installed capacity has continued to increase more than the net number of operating reactors. This is a result of the combined effects of larger units replacing smaller ones. (In 1989, the average size of an operational nuclear reactor was about 740 MW, while that number has increased to 897.5 MW in 2022). Technical alterations raised capacity at existing plants resulting in larger electricity output, a process known as uprating.[23] In the U.S. alone, the Nuclear Regulatory Commission (U.S.NRC) has approved 171 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.[24]

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 backfitting costs soar and alternatives become cheaper.

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

24 - U.S.NRC, "Approved Applications for Power Uprates", U.S. Nuclear Regulatory Commission, Updated 19 November 2021, see http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 18 July 2022.

Figure 6 · World Nuclear Reactor Fleet, 1954–2022



Sources: WNISR, with IAEA-PRIS, 2022

Note
Changes in the database regarding closing dates of reactors or LTO status slightly change the shape of this graph from previous editions. In particular, the previous "maximum operating capacity" of 2006 (overtaken in July 2019) is now at 367 GW.

As of mid-2022, the International Atomic Energy Agency (IAEA) continues to count 33 units in Japan in its total number of 440 reactors "in operation" in the world.[25] No nuclear electricity was generated in Japan between September 2013 and August 2015, and as of 25 July 2022, only seven of ten reactors with a valid operating license were operating. Nuclear plants provided 7.2 percent of the electricity in Japan in 2021 up from 5.1 percent in 2020 (for details see Japan Focus).

The WNISR reiterates its call 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" is misleading.

The IAEA does have a reactor-status category called "Long-term Shutdown" or LTS.[26] Under the IAEA's definition, a reactor is considered in LTS, if it has been shut down for an "extended period (usually more than one year)", and in early period of shutdown either restart is not being "aggressively pursued" or "no firm restart date or recovery schedule has been established". The IAEA currently lists one single reactor in the LTS category: the Rajasthan-1 reactor in India,

25 - IAEA, "Power Reactor Information System", International Atomic Energy Agency, Undated, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, accessed 22 July 2021.

26 - See IAEA Glossary, at www.iaea.org/pris/Glossary.aspx, accessed 22 July 2021.

which has not generated power since 2004 and is considered permanently closed in 2004 by WNISR. It was moved from the operating to the LTS category by the IAEA in June 2022.

The IAEA criteria are vague and hence subject to interpretation. What exactly are *extended* periods? What is *aggressively* pursuing? What is a *firm* restart date or recovery schedule? 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 2022, leads to classifying 29 units in LTO—all considered "in operation" by the IAEA—three more than in WNISR2021, of which 23 in Japan, three in India (Madras-1, Tarapur-1 & -2), two in Canada (Bruce-6 and Darlington-3, scheduled to restart, after refurbishment, in 2023 and 2024), and one in South Korea (Hanbit-4).

One reactor that re-entered the LTO category in Japan as of July 2021 (Ikata-3) was reconnected to the grid in October 2021.

IAEA vs. WNISR Assessment

Figure 7 presents the evolution of the number and capacity of the world reactor fleet "in operation" as reported by the IAEA vs. WNISR.

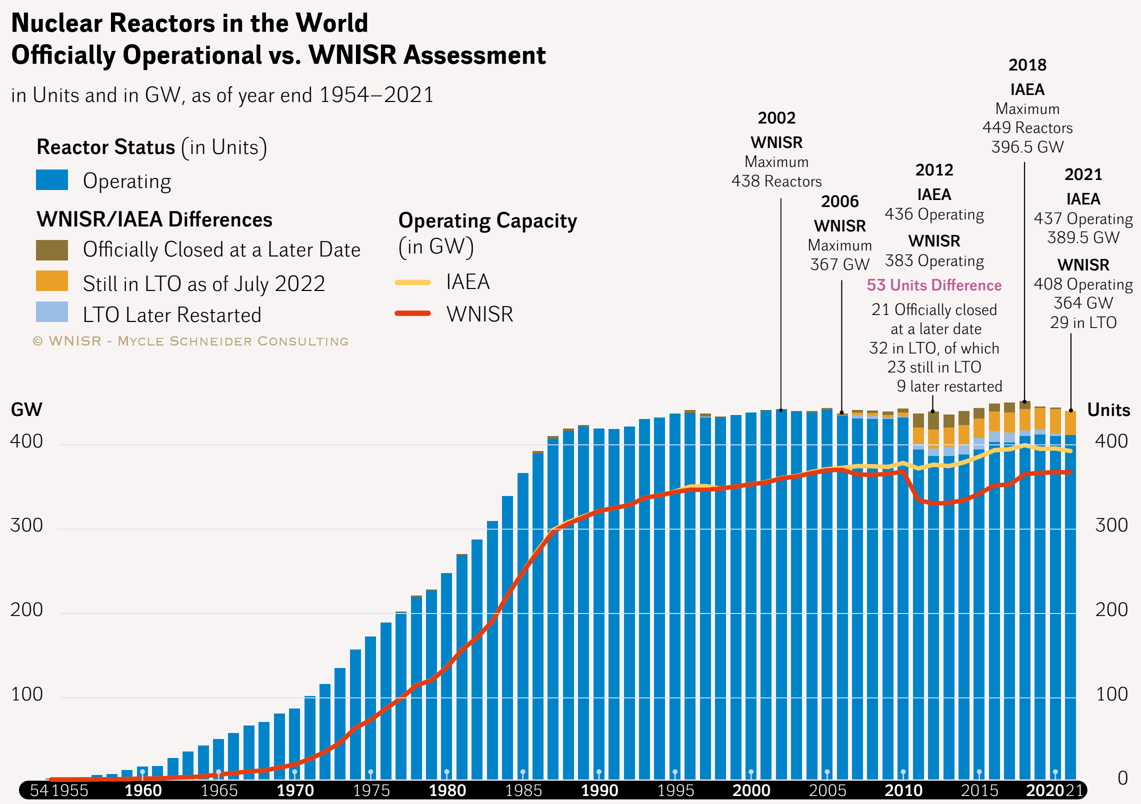
"The evolution of the world nuclear fleet according to the IAEA shows a peak of officially operating reactors, both in terms of number and capacity, in 2018."

The evolution of the world nuclear fleet according to the IAEA shows a peak of officially operating reactors, both in terms of number and capacity, in 2018, while WNISR analysis shows the number of units peaking as early as 2002 and capacity in 2006.

WNISR's assessment of "operating" reactors shows significant differences with IAEA statistics since the beginning of the Fukushima disaster in 2011. The following section provides a detailed explanation and justification of the differences.

Although not the only case, the Japanese fleet provides the main and more visible differences, especially over the past decade. As of December 2021, the IAEA included 33 units in Japan in its total number of 437 reactors "in operation" in the world. However, 23 of these reactors have not produced electricity since 2010–2011 (of which three since 2007). When subsequently the decision is taken to close a reactor—whether or not it was previously considered in LTO—the closure status starts with the day of the last electricity generation, and the WNISR statistics are retroactively modified accordingly. Those are the reactors "Officially closed at a later date" in Figure 7.

Figure 7 · World Nuclear Reactor Fleet – IAEA vs WNISR 1954–2021



Sources: IAEA-PRIS and WNISR

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). On the other hand, the Swiss research reactor in Lucens is not included. Reactors classified as in "Long-term Shutdown" (LTS) by the IAEA are not represented here. Until July 2022, the IAEA list of operating reactors also included Rajasthan-1 in India, which has not produced since 2004, but has only been classified as "Long-term Shutdown" in June 2022 (with an LTS start date retroactively set to October 2004).[27]

Applying this definition to the world nuclear reactor fleet, as of 31 December 2021, leads to classifying 29 units as LTO —all considered "in operation" by the IAEA.

Besides the 23 Japanese reactors, the LTO definition also applies to three units in India (Madras-1, Tarapur-1 & -2), two in Canada (Bruce-6 and Darlington-3), and one in South Korea (Hanbit-4).

- Bruce-6 and Darlington-3 are under refurbishment since January and July 2020 respectively. They are scheduled to come back online in 2023 and 2024 respectively (see section on Canada in Annex 1).

27 - IAEA - PRIS, "PRIS - Reactor Details - Rajasthan-1", 8 August 2022, see https://pris.iaea.org/pris/CountryStatistics/ReactorDetails.aspx?current=302, accessed 9 August 2022.

- Madras-1 is shutdown since January 2018 to carry out major repair work and has not restarted as of mid-2022. Tarapur-1 and -2, the two oldest reactors in the world, are "under project mode...for extensive health assessment of primary system" since April and August 2020 respectively (see India Focus).[28]
- Hanbit-4, impacted by various ageing issues, has not been operating since May 2017. As of mid-2021, it was scheduled to be reconnected to the grid in August 2021, but this did not happen (see South Korea Focus).

The biggest difference is found as of the end of 2012, with 53 units less operating according to WNISR criteria, detailed in Table 1.

Table 1 – WNISR Rationale for the Classification of 53 Reactors as Non-Operational as of end 2012

<table>
<tr><th></th><th colspan="2">Officially Closed at Later Date
21 Reactors</th><th>Still in LTO
23 Reactors</th><th>Restarted from LTO
9 Reactors</th></tr>
<tr><td rowspan="2">Typology</td><td colspan="2">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 an LTO period). Most of those reactors were considered "in operation" for many years before their official closure date.</td><td rowspan="2">Reactors not restarted since 2012, officially "in operation" as of 31 December 2021.</td><td rowspan="2">Reactors in LTO as of December 2012 Restarted prior to 31 December 2021</td></tr>
<tr><td>Reactors considered closed in 2012</td><td>Reactors in LTO prior to closure</td></tr>
<tr><td>Japan</td><td>6 Reactors
Fukushima Daiichi 5–6
Fukushima Daini 1–4
Officially Closed
in 2013 and 2019</td><td>11 Reactors
Last production in 2010–2012
Officially closed 2015–2019</td><td>23 Reactors
Last production
2006–2012</td><td>8 Reactors
Restarted 2015–2021</td></tr>
<tr><td>South Korea</td><td></td><td></td><td></td><td>1 Reactor
Wolsong-1
Restarted in 2015</td></tr>
<tr><td>Spain</td><td>1 Reactor
Santa Maria de Garoña
Last production in 2012
Officially Closed in 2017*</td><td></td><td></td><td></td></tr>
<tr><td>U.S.</td><td>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</td><td></td><td></td><td></td></tr>
</table>

Sources: IAEA-PRIS and WNISR, 2022

Note: *Garoña was subsequently considered in Long-term Shutdown (LTS) 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 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.

28 - IAEA, "Operating Experience with Nuclear Power Stations in Member States – 2022 Edition", 2022.

OVERVIEW OF CURRENT NEW-BUILD

As of 1 July 2022, 53 reactors are considered as under construction, the same number the WNISR reported a year ago, but 16 fewer than in 2013 (five of those units have subsequently been abandoned). The number includes 21 units (40 percent) being built in China.

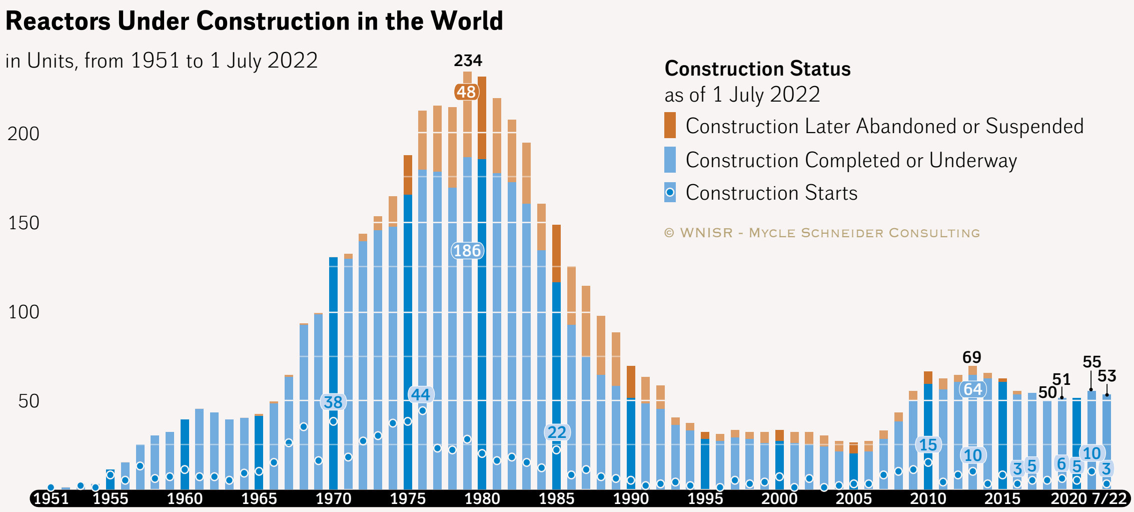
Four in five reactors are built in Asia or Eastern Europe. In total, 15 countries are building nuclear plants, two less (Finland and Pakistan) than in WNISR2021 (see Building vs. Vendor Countries.)

However, only four countries—China, India, Russia, and South Korea—have construction ongoing at more than one site (see Annex 3 for details). Since mid-2021, seven new construction sites were launched worldwide, including six in China. One construction start took place in India (Kudankulam-6).

The 53 reactors listed as under construction by mid-2022 compare poorly with a peak of 234—totaling more than 200 GW—in 1979. However, many (48) of those projects listed in 1979 were never finished (see Figure 8). 2005, with 26 units under construction, was the lowest since the early nuclear age in the 1950s.

Compared to the year before, the total capacity of the 53 units under construction in the world in mid-2022 slightly decreased by just 0.8 GW to 53.3 GW, with an average unit size of 1,005 MW.

Figure 8 · Nuclear Reactors "Under Construction" in the World (as of 1 July 2022)



Sources: WNISR, with IAEA-PRIS, 2022

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 under construction since 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. There is no indication of grid connection of the second module (see China Focus for details).

BUILDING VS. VENDOR COUNTRIES

As of mid-2022, China has by far the most reactors (21 units) under construction in the world. However, China 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 20 units under construction in the world as of mid-2022 of which only three domestically but 17 in seven countries, including four each in China and India and three in Turkey.[29] It is uncertain at this point to what extent these projects will be impacted by the various layers of sanctions imposed on Russia and other consequential geopolitical developments following the invasion of Ukraine.

Besides Russia's Rosatom, there are only French and South Korean companies building abroad (see Table 2 and Figure 9).

Table 2 – Nuclear Reactors "Under Construction" (as of 1 July 2022)[30]

Country	Units (Domestic Design)	Other Vendor	Capacity (MW net)	Construction Start	Grid Connection	Units Behind Schedule
China	21 (17)	Russia: 4	20 932	2012 – 2022	2022 – 2028	3
India	8 (4)	Russia: 4	6 028	2004 – 2021	2023 – 2027	6[(a)]
Russia	3 (3)	–	2 650	2018 – 2021	2023 – 2026	
South Korea	3 (3)	–	4 020	2013 – 2018	2023 – 2025	3
Turkey	3 (0)	Russia: 3	3 342	2018 – 2021	2024 – 2026	1
Bangladesh	2 (0)	Russia: 2	2 160	2017 – 2018	2023 – 2024	
Slovakia	2 (0)	Russia: 2[(b)]	880	1985	2022 – 2023	2
UAE	2 (0)	South Korea: 2	2 690	2014 – 2015	2023	2
U.K.	2 (0)	France: 2	3 260	2018 – 2019	2027 – 2028	2
U.S.	2 (2)	–	2 234	2013	2023	2
Argentina	1 (1)	–	25	2014	2027	1
Belarus	1 (0)	Russia: 1	1 110	2014	2022	1
France	1 (1)	–	1 630	2007	2023	1
Iran	1 (0)	Russia: 1	974	1976	2024	1
Japan	1 (1)	–	1 325	2007	2025?	1
Total	53		53 260	1976 - 2022	2022 – 2028	26
Total per Vendor Country: Russia: 20 - China: 17 - South Korea: 5 - India: 4 - France: 3 - U.S.: 2 - Argentina: 1 - Japan: 1						

Sources: Various, compiled by WNISR, 2022

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 India Focus.

(b) - The Mochovce Units 3 and 4 are a Russian VVER design being completed by Czech-led consortium.

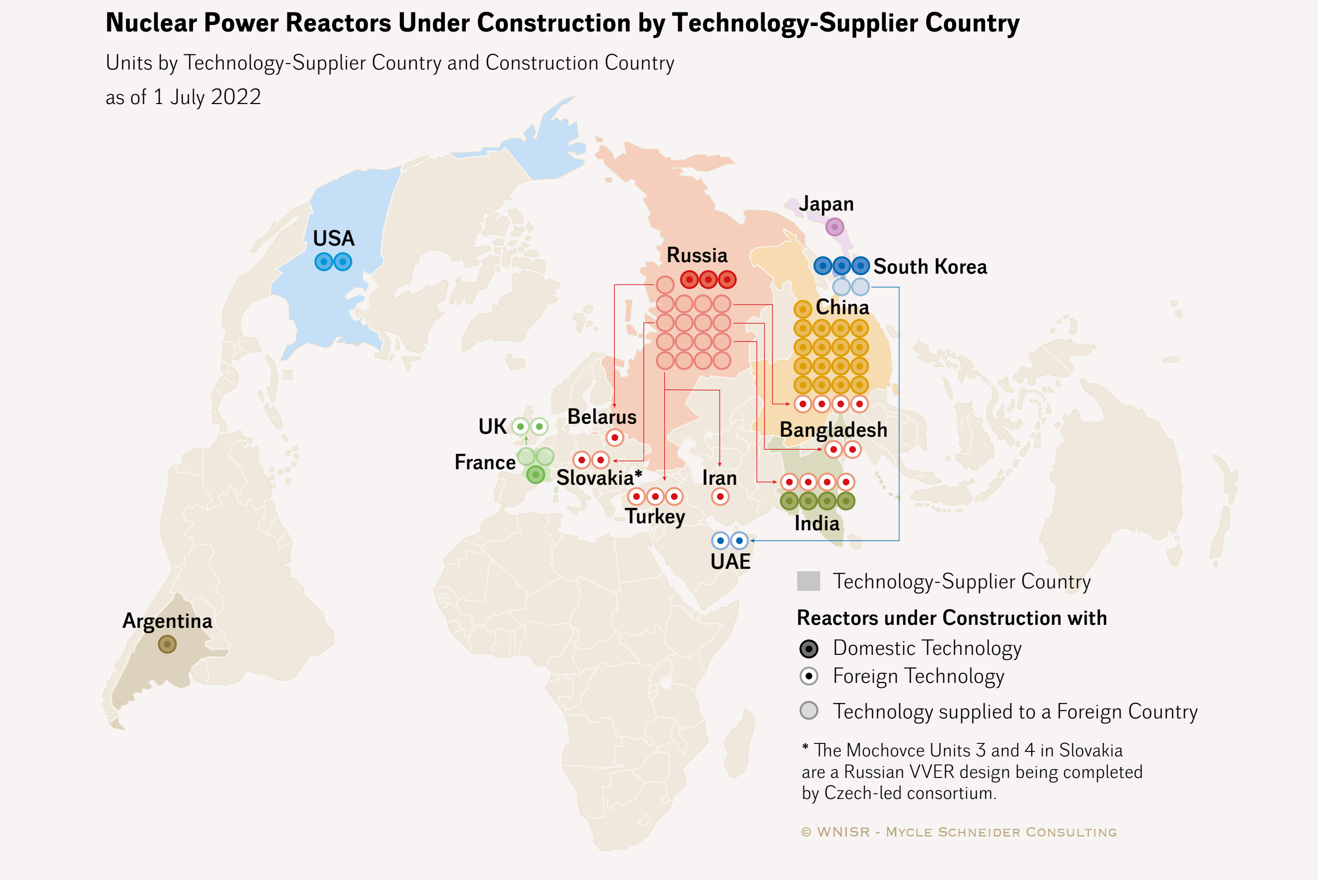
This table does not contain suspended or abandoned constructions.

It 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 under construction since 2012 has two reactors on the site and is therefore counted as two units as of WNISR2020. Grid connection of the first unit of the twin reactor officially took place on 20 December 2021. There is no indication of grid connection of the second unit.

29 - Construction of a fourth unit started at the Akkuyu site in Turkey on 21 July 2022, see WNISR, "Akkuyu-4 in Turkey: Second Construction Start in a Week for the Russian Nuclear Industry—Anyways 4", 24 July 2022, see https://www.worldnuclearreport.org/Akkuyu-4-in-Turkey-Second-Construction-Start-in-a-Week-for-the-Russian-Nuclear.html, accessed 9 September 2022.

30 - For further details, see Annex 3.

Figure 9 · Nuclear Reactors "Under Construction" by Technology-Supplier Country



Sources: WNISR, with IAEA-PRIS, 2022

CONSTRUCTION TIMES

Construction Times of Reactors *Currently Under Construction*

A closer look at projects listed as "under construction" as of 1 July 2022 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 53 reactors being built, an average of 6.8 years has passed since construction start—slightly lower than the mid-2021 average of seven years— and many remain far from completion.
- *All* reactors under construction in at least 10 of the 15 countries have experienced mostly year-long delays. At least half (26) of the building projects are 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. Particular uncertainty remains over construction in China because of lack of access to information. While it is unclear what will happen with Russian designed and/or implemented projects in seven other countries, as sanctions have or will likely have an impact on supply chains.

- Of the 26 reactors clearly documented as behind schedule, at least 14 have reported *increased* delays and two have reported *new* delays over the past year.
- WNISR2020 noted a total of 19 reactors scheduled for startup in 2021, and at the beginning of 2021, 16 were still planned to be connected to the grid but only six of these made it, while the other 10 were delayed at least into 2022.
- Construction starts of two projects date back 37 years, Mochovce-3 and -4 in Slovakia, and their grid connection has been further delayed, currently to late 2022 and 2023. Bushehr-2 in Iran originally started construction in 1976, over 45 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2024.
- Six additional reactors have been listed as "under construction" for a decade or more: 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.

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 regulations were less stringent. As Figure 10 illustrates, construction times of reactors completed in the 1970s and 1980s were quite homogenous, while in the past two decades they have varied widely.

The seven units completed in 2019–2021 in China took on average 6.4 years to build, while the four projects finalized in Russia took a mean 11.4 years (compared to 15 years for the period 2018–2020).

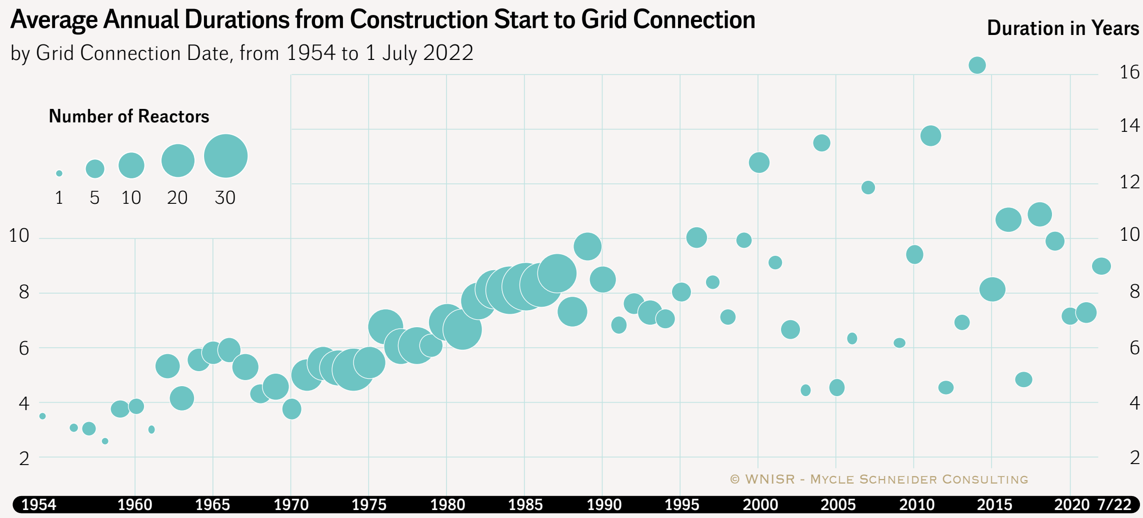
As Figure 11 shows for the period 2019–2021, the longest construction times for those two countries were for the EPR at Taishan-2 (9.2 years), the first reactor of the two HTR module at Shidao Bay 1 (9.1 years) and the floating reactors Academic Lomonosov-1 and -2 (12.1 years).

The case of the twin "floating" reactors Akademik-Lomonosov is particularly interesting. These are small 30-MW reactors meant to demonstrate a new generation of Small Modular Reactors (SMRs), smaller, cheaper, and faster to build. However, construction has taken longer than any other reactor that has come on-line over those three years and took about 3.5 times as long as originally projected; a little before construction of the ship began in 2007, Rosatom announced that the plant would begin operating in October 2010.[31] But that happened only in December 2019. Not surprisingly, the "nuclear barge" has become more expensive, from an

31 - Rosatom, "The first offshore nuclear heat and electrical power plant of small capacity is planned to operate in October 2010 in Severodvinsk (Arkhangelsk district)", Press Release, 15 December 2006; and IPFM, "Global Fissile Material Report 2007—Developing the technical basis for policy initiatives to secure and irreversibly reduce stocks of nuclear weapons and fissile materials", Second Report of the International Panel on Fissile Materials, Program on Science and Global Security, Princeton University, 1 October 2007, see http://fissilematerials.org/publications/2007/10/global_fissile_material_report_1.html, accessed 3 September 2020.

initial estimate of around 6 billion rubles (US$$_{2007}$232 million)[32] to at least 37 billion rubles as of 2015 (US$$_{2015}$740 million),[33] or close to US$25,000 per installed kilowatt, almost twice as costly as the most expensive Generation III reactors.[34]

Figure 10 · Average Annual Construction Times in the World



Sources: WNISR, with IAEA-PRIS, 2022

The mean time from construction start to grid connection for the six reactors started up in 2021 was 7.1 years, comparable to 2020 (7.2 years), a clear improvement over the 9.9 years in 2019. In the case of the five units connected in the first half of 2022, the duration was nine years.

"Over the three years 2019–2021, only two of 17 units started up on-time."

While mean construction times have been declining recently, over the three years 2019–2021, only two of 17 units started up on-time. Those are Tianwan-4 and -5 in China, a Russian-designed but mainly Chinese-built VVER-1000 (model V-428M), that the designers claim to belong to Gen III classification, but few details are known. The two Chinese units Hongyanhe-5 and Yangjiang-6 were completed with minor delays in 6.2 and 5.5 years respectively. These are ACPR1000 reactors, designed by China General Nuclear Corp. (CGN) that claims contain at least ten improvements making them a Gen III design[35].

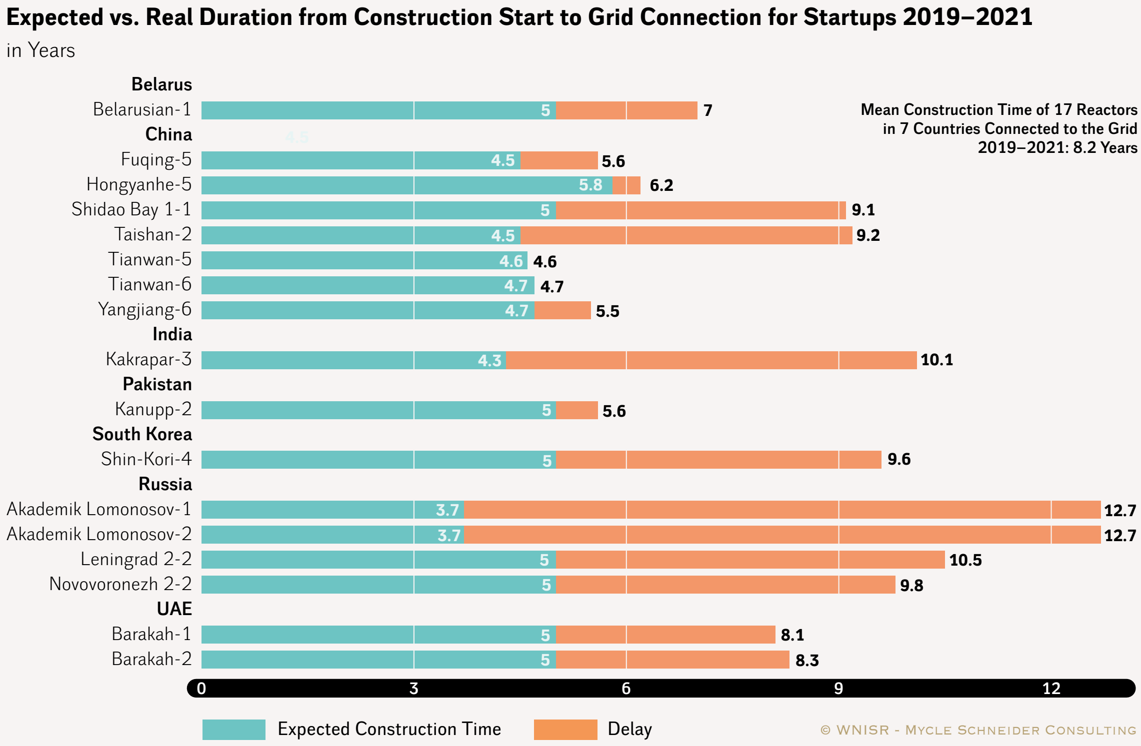
32 - *WNN*, "Russian floating reactor construction starts", 17 April 2007, see https://www.world-nuclear-news.org/Articles/Russian-floating-reactor-construction-starts, accessed 3 September 2020.

33 - Charles Digges, "New documents show cost of Russian floating nuclear power plant skyrockets", Bellona, 25 May 2015, see http://bellona.org/news/nuclear-issues/2015-05-new-documents-show-cost-russian-nuclear-power-plant-skyrockets, accessed 28 December 2015.

34 - The current cost estimate—including financing costs—of the Flamanville-3 EPR is about US$13,700/kW (see France Focus).

35 - Caroline Peachey, "Chinese reactor design evolution", *NEI Magazine*, 22 May 2014, see https://www.neimagazine.com/features/featurechinese-reactor-design-evolution-4272370/, accessed 14 August 2019.

Figure 11 · Delays for Units Started Up 2019–2021



Sources: Compiled by WNISR with IAEA-PRIS, 2022

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.

The longer-term perspective confirms that short construction times remain the exceptions. Ten countries completed 62 reactors over the decade 2012–2021—of which 37 in China alone—with an average construction time of 9.2 years (see Table 3). That is an improvement of 0.7 years over the mean construction time in the decade 2011–2020.

Table 3 – Duration from Construction Start to Grid Connection 2012–2021

Construction Times of 62 Units Started-up 2012–2021				
Country	Units	Construction Time (in Years)		
		Mean Time	Minimum	Maximum
China	37	6	4.1	9.2
Russia	9	17.9	8.1	35.1
South Korea	5	6.4	4.2	9.6
India	3	12	10.1	14.2
Pakistan	3	5.6	5.5	5.6
UAE	2	8.2	8.1	8.3
Argentina	1	33.0	33.0	
Belarus	1	7.0	7.0	
U.S.	1	42.8	42.8	
World	62	9.2	4.1	42.8

Sources: Various, compiled by WNISR, 2022

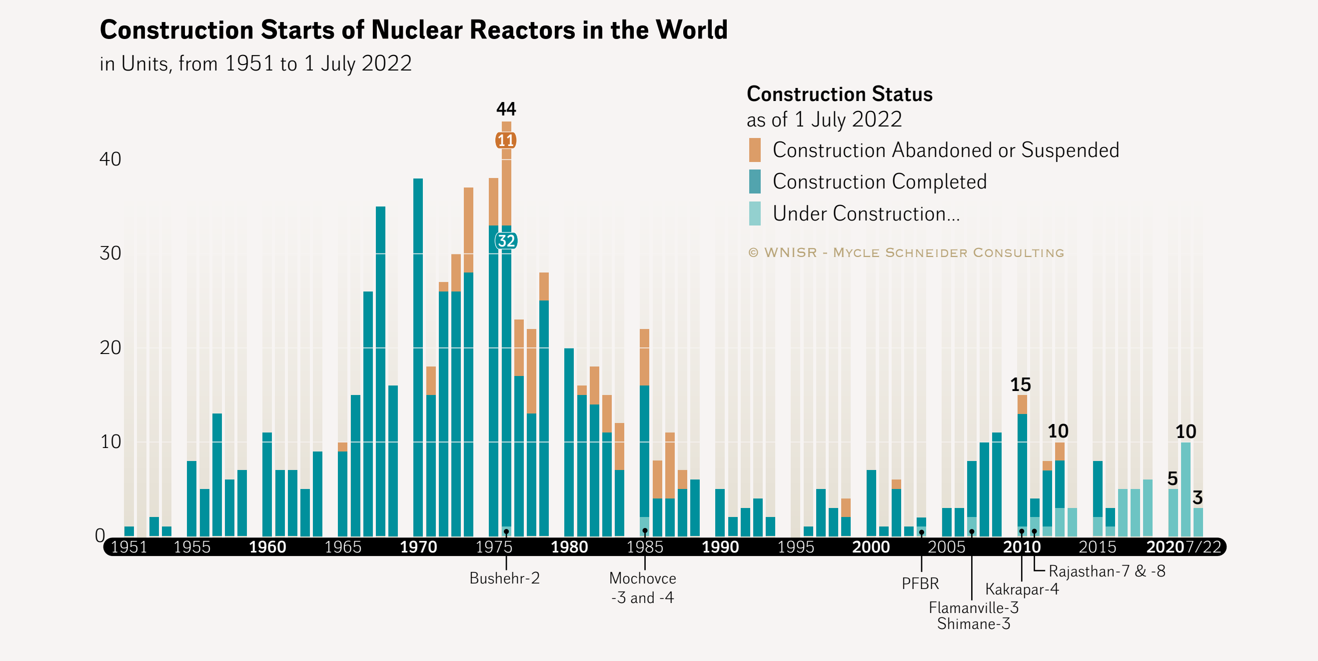
CONSTRUCTION STARTS AND CANCELLATIONS

The number of annual construction starts[36] 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 12 and Figure 13). That number dropped to five in 2020—including four in China—while building started on ten units in 2021—including six in China. The other four units are implemented by the Russian nuclear industry in India (2), in Turkey and domestically, and two of the construction starts in China were also by the Russian industry. In other words, of the global total of ten, six reactors were by Russian builders and four by Chinese industry.

Three reactors got underway in the world in the first half of 2022, all of them in China, two of which are of Russian design. Chinese and Russian government owned or controlled companies launched all of the 18 reactor constructions in the world over the 30-month period from the beginning of 2020 to mid-2022.

36 - 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.

Figure 12 · Construction Starts in the World



Sources: WNISR, with IAEA-PRIS, 2022

Notes:

Construction of Bushehr-2, started in 1976, was considered abandoned in earlier versions of this figure. As construction was restarted in 2019, it now appears as "Under Construction".

The Chinese project at Shidao Bay-1 is considered as two reactors, and construction starts in 2012 reflect this change.

Over the decade 2012–2021, construction began on 63 reactors in the world, of which half (31) in China. Three of these building sites have been abandoned over the period (Baltic-1 in Russia, V.C. Summer-2 and -3 in the U.S.). As of mid-2022, 19 of the remaining 60 units have started up, while 41 remain under construction.

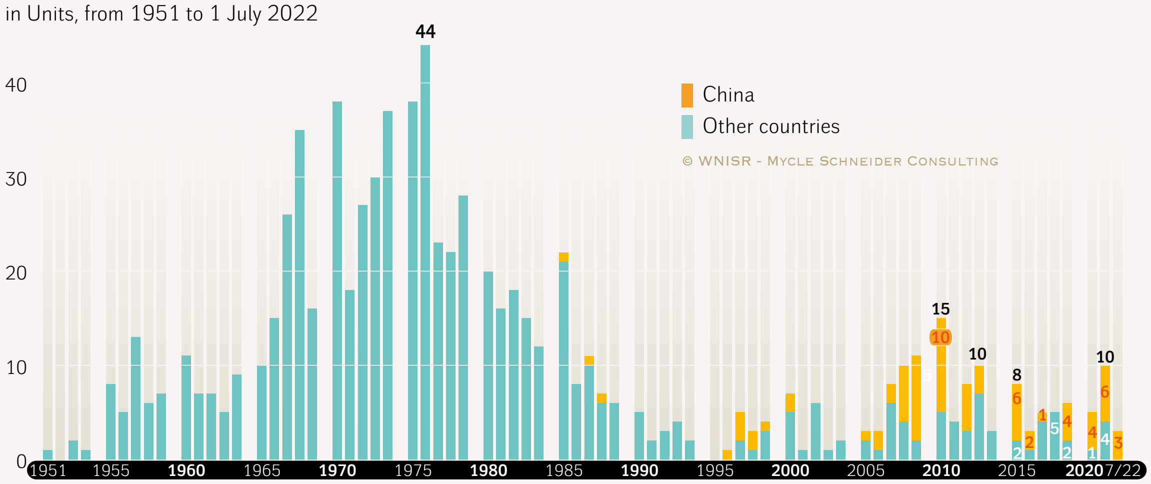
"The two V.C. Summer units, abandoned in July 2017 after four years of construction and following multi-billion-dollar investment, are only the latest in a long list of failed nuclear power plant projects."

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 and three in the first half of 2022 (see Figure 13). 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 2021, 53 reactors with a total capacity of 49.7 GW were operating and 20 units (19.2 GW) were under construction (for details, see China Focus).

Figure 13 · Construction Starts in the World/China

Construction Starts of Nuclear Reactors in the World

in Units, from 1951 to 1 July 2022



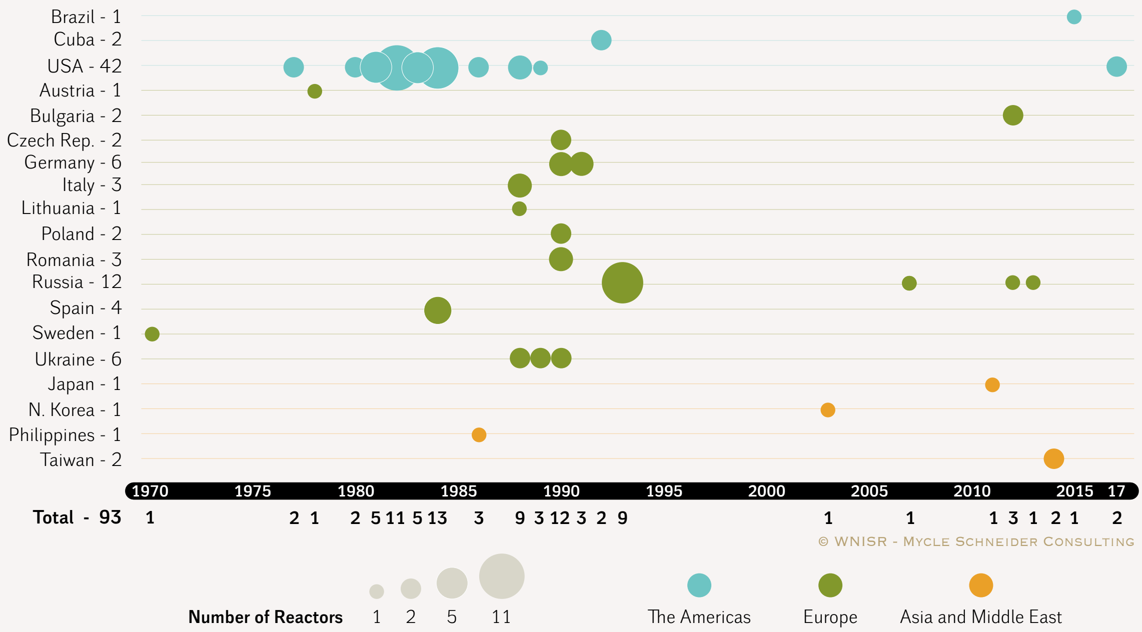
Sources: WNISR, with IAEA-PRIS, 2022

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 nuclear power plant projects.

Figure 14 · Cancelled or Suspended Reactor Constructions

Abandoned Reactor Constructions from 1970 to 1 July 2022

in Units by Cancellation Year and Country



Sources: WNISR, with IAEA-PRIS, 2022

Note: This graph only includes constructions that had officially started with the concreting of the base slab of the reactor building.

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 14). The United States alone accounted for 138 of these order cancellations.[37]

Of the 790 reactor constructions launched since 1951, at least 93 units in 19 countries had been abandoned or suspended, as of 1 July 2022. This means that 12 percent—or one in eight—of nuclear constructions have been abandoned.

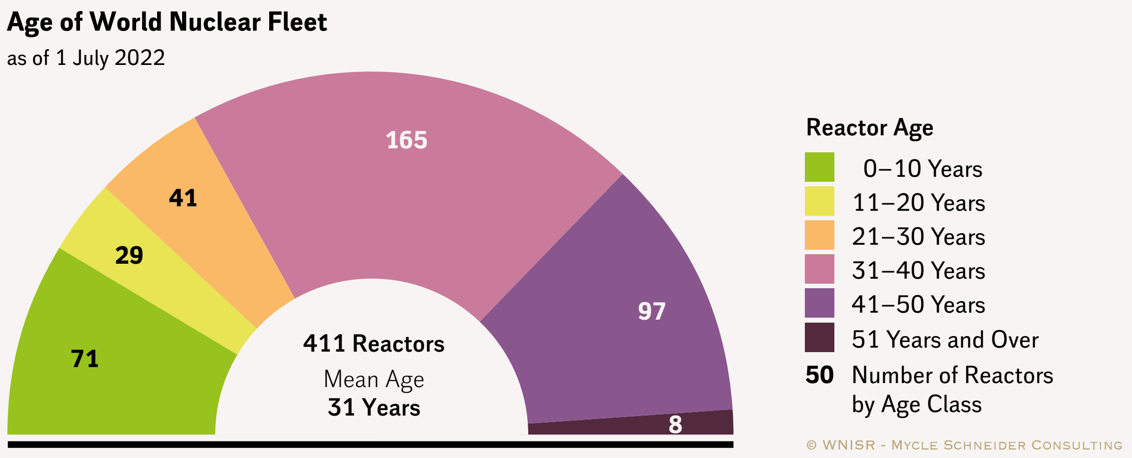
Close to three-quarters (66 units) of all cancelled projects were in four countries alone—the U.S. (42), Russia (12), Germany and Ukraine (six each). Some units were 100-percent completed—including Kalkar in Germany and Zwentendorf in Austria—before it was decided not to operate them.

OPERATING AGE

In the absence of significant, successful new-build over many years, the average age (from grid connection) of operating nuclear power plants has been increasing since 1984, and as of mid-2022 is 31 years, up from 30.9 years in mid-2021 (see Figure 15).[38]

A total of 270 reactors, two-thirds of the world's operating fleet, have operated for 31 or more years, including 105—more than one in five—for at least 41 years.

Figure 15 · Age Distribution of Operating Reactors in the World



Sources: WNISR, with IAEA-PRIS, 2022

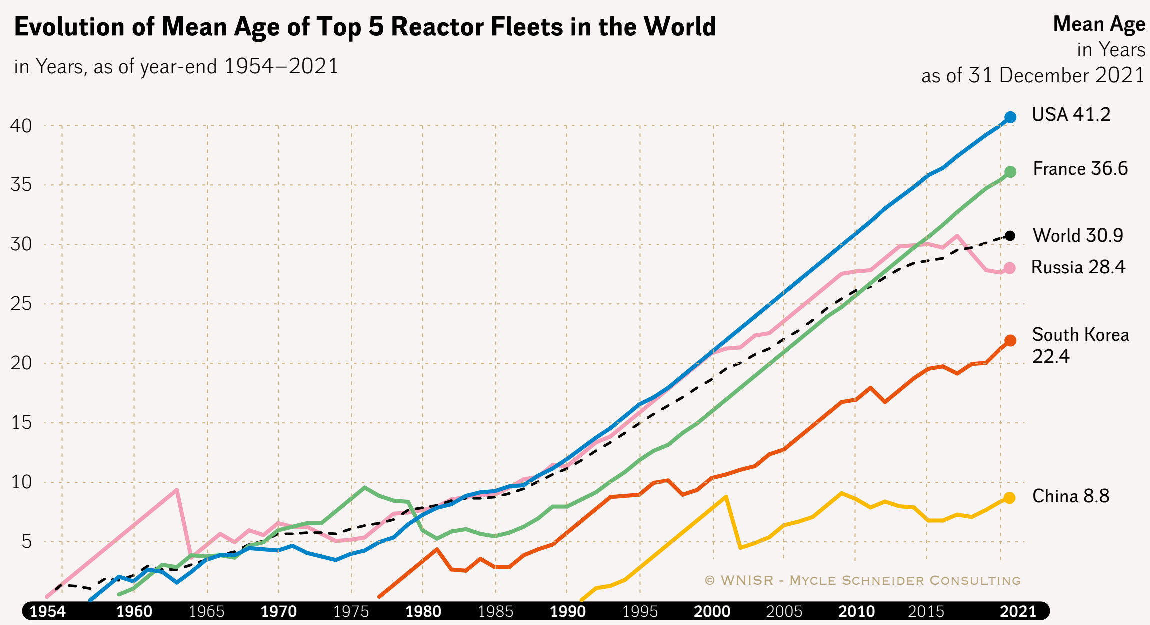
In 1990, the average age of the operating reactors in the world was 11.3 years; in 2000, it was 18.8 years and it stood at 26.3 years in 2010. The leading nuclear nation is also leading the age

37 - CEA, "Elecnuc—Nuclear Power Plants in the World", French Alternatives Energies and Atomic Energy Commission, 2002. The section "cancelled orders" has disappeared after the 2002 edition.

38 - 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.

pyramid. The average age of reactors in the U.S. passed 40-years in 2020 and reached 41.2 years as of the end of 2021. France's fleet now exceeds 36 years. Russia inverted the curve starting in 2016 and its average fleet age of 28.4 years as of the end of 2021 remains 1.8 years below the 2015-peak. South Korea's reactors at 22.4 years remain almost half as old as the U.S. fleet, and China is the obvious newcomer with an average fleet age of just 8.8 years. (See Figure 16).

Figure 16 · Reactor-Fleet Age of Top 5 Nuclear Generators



Sources: WNISR, with IAEA-PRIS, 2022

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."[39]

As of mid-2022, 97 U.S. units had received a 20-year license extension, no further applications were under NRC review. Ten units with renewed licenses were closed early, and two applications for three reactors were withdrawn as Crystal River was closed; the two Diablo Canyon units are scheduled to close when their current license expires in 2024–2025, although their closure might be deferred until 2029 and 2030 (see United States Focus). Three additional applications for five reactors are expected in 2023–2024.[40]

39 - 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, U.S. Nuclear Regulatory Commission, 22 June 2021, see https://www.nrc.gov/docs/ML2111/ML21117A007.pdf, accessed 11 August 2021.

40 - U.S. NRC, "Status of License Renewal Applications and Industry Activities", Nuclear Regulatory Commission, Updated 12 January 2022, see http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 26 July 2022.

So far, the NRC has granted Subsequent Renewed Operating Licenses to six reactors, which permit operation from 60 to 80 years. A further nine reactors have their applications still under review.[41]

"Only nine of the 41 units that have been closed in the U.S. had reached 40 years on the grid."

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 mainly for economic reasons. In other words, at least a quarter of the 133 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 92 currently operating plants, 47 units have already operated for 41 years and six have been on the grid for 50 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-2022 mean age of the U.S. operational fleet exceeding 41.5 years (see Figure 40 in 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 37 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 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.

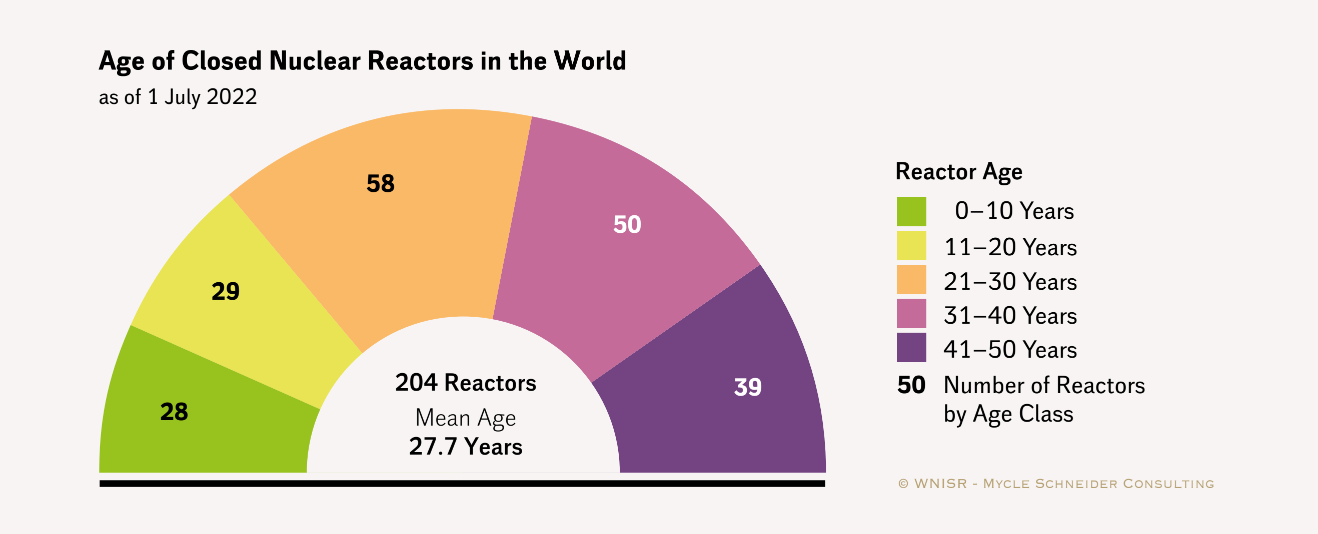
EDF's approach to lifetime extension has been reviewed by ASN and its Technical Support Organization. In February 2021, ASN granted a conditional generic agreement to lifetime extensions of the 32 reactors of the 900 MW series. However, lifetime extensions beyond 40 years require reactor-specific licensing procedures involving public inquiries in France.

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.

In assessing the likelihood of reactors 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 204 units that have already closed (see Figure 15 and Figure 17). In total, 89 of these units operated for 31 years or more, and, of those 89, 39 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.

41 - U.S. NRC, "Status of Subsequent License Renewal Applications", Nuclear Regulatory Commission, as of 9 June 2022, see https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html, accessed 26 July 2022.

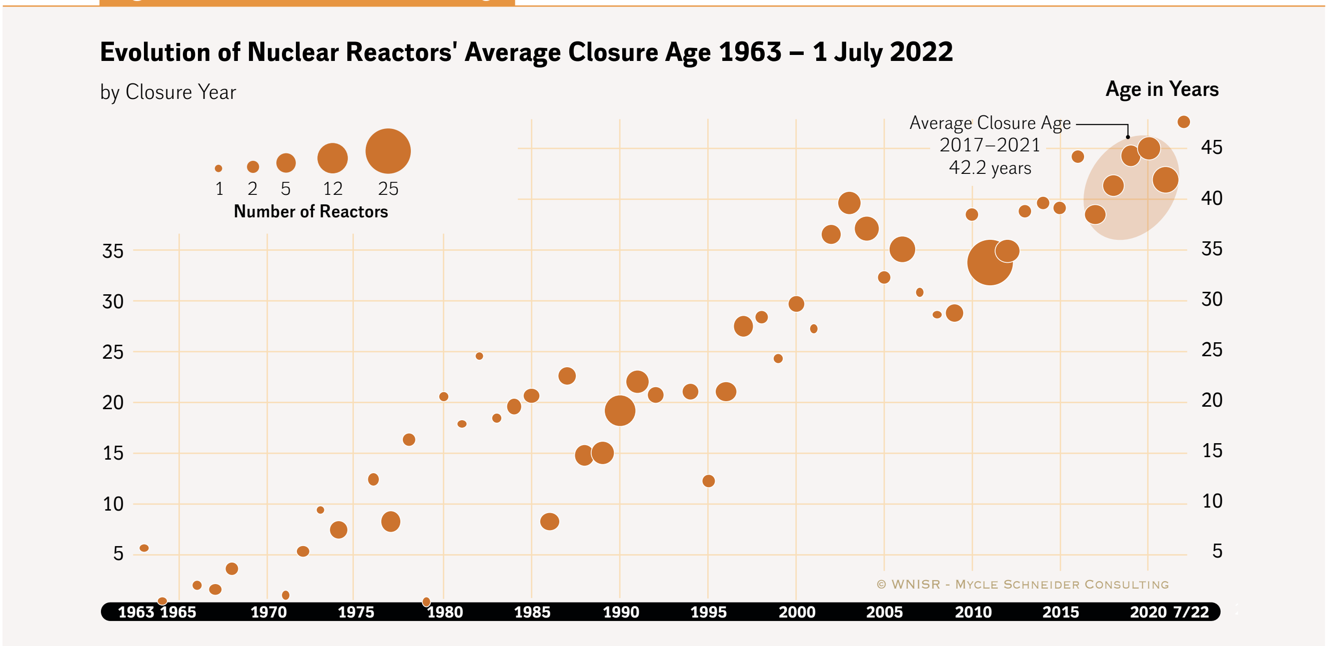
Figure 17 · Age Distribution of Closed Nuclear Power Reactors



Sources: WNISR, with IAEA-PRIS, 2022

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 2017 and 2021 was 42.2 years (see Figure 18).

Figure 18 · Nuclear Reactor Closure Age



Sources: WNISR, with IAEA-PRIS, 2022

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 accidents 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, including in Belgium, Switzerland, and Taiwan. Some of the main nuclear countries closed their respective then oldest unit 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.

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 19), assumes a general lifetime of 40 years for worldwide operating reactors—not including reactors in Long-Term Outage (LTO).

Forty years corresponds to the design lifetimes of most operating reactors. Some countries have legislation or policy in place—including Belgium, South Korea (in the course of being changed by the incoming administration)—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. APR1400, EPR). For the 115 reactors that have passed the 40-year lifetime as of mid-2022, we assume they will operate to the end of their licensed, extended operating time.

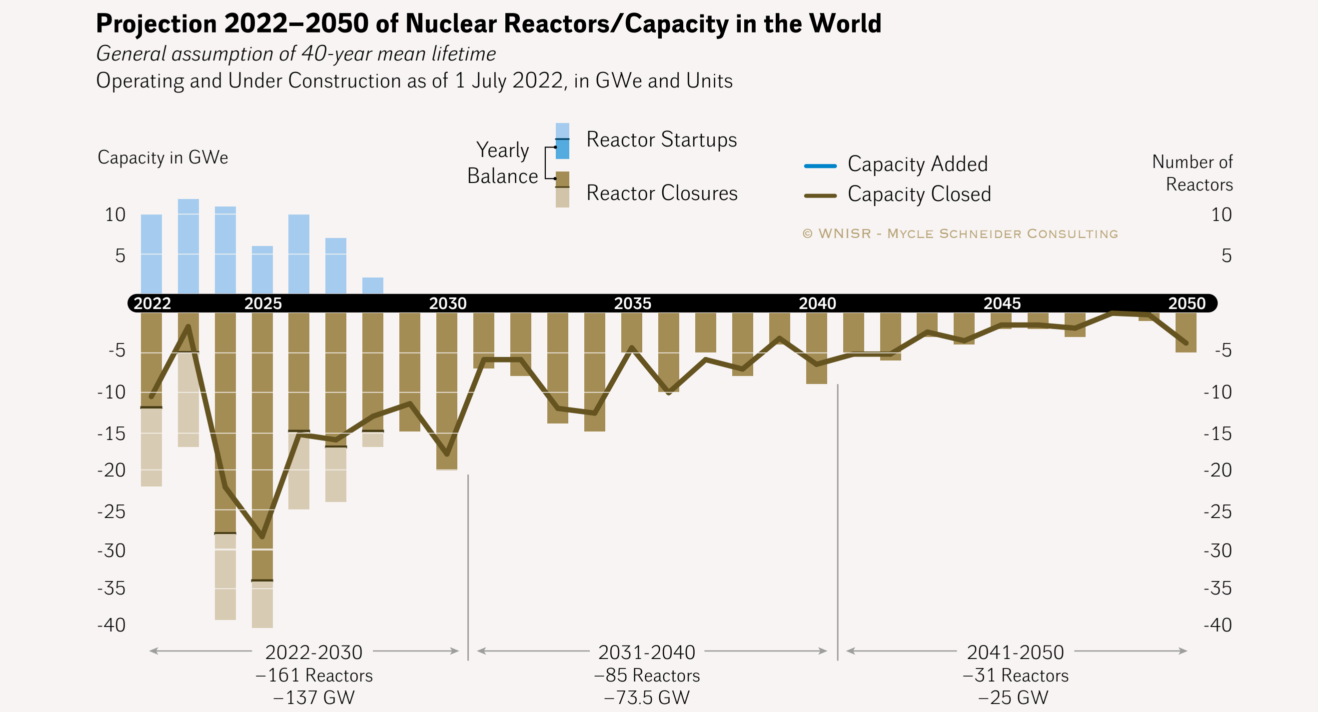
A second scenario (Plant Life Extension or PLEX Projection, see Figure 20) takes into account *all* already-authorized lifetime extensions and assumes that the respective reactors will operate until the expiration of their license.

The lifetime projections allow for an evaluation of the number of plants 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 12 additional reactors (compared to the end of 2021 status) would have to be commissioned or restarted prior to the end of 2022 in order to maintain the status quo of operating units. Without additional startups, or last-minute lifetime extensions as envisaged in Germany and in Belgium, installed nuclear capacity would decrease by 10.6 GW by the end of 2022.

In the decade to 2030, in addition to the units currently under construction, 161 new reactors (137 GW)—18 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 (63 startups between 2012 and 2021).

Figure 19 · The 40-Year Lifetime Projection



Sources: Various sources, compiled by WNISR, 2022

Notes pertaining to Figure 19, Figure 20 and Figure 21:

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

Restarts or closures amongst the 29 reactors in LTO as of 1 July 2022 are not represented here although at least two Canadian reactors that are in LTO are set to be restarted, and thus later closed as well.

The figures also take into account current political decisions or legally binding obligations as of end of August 2022 to close reactors prior to 40 years (Germany, South-Korea). These decisions are under discussions in both countries and might be reversed after the editorial deadline of WNISR2022, as it is the case in Belgium, with discussions on a ten-year lifetime extension for two reactors.

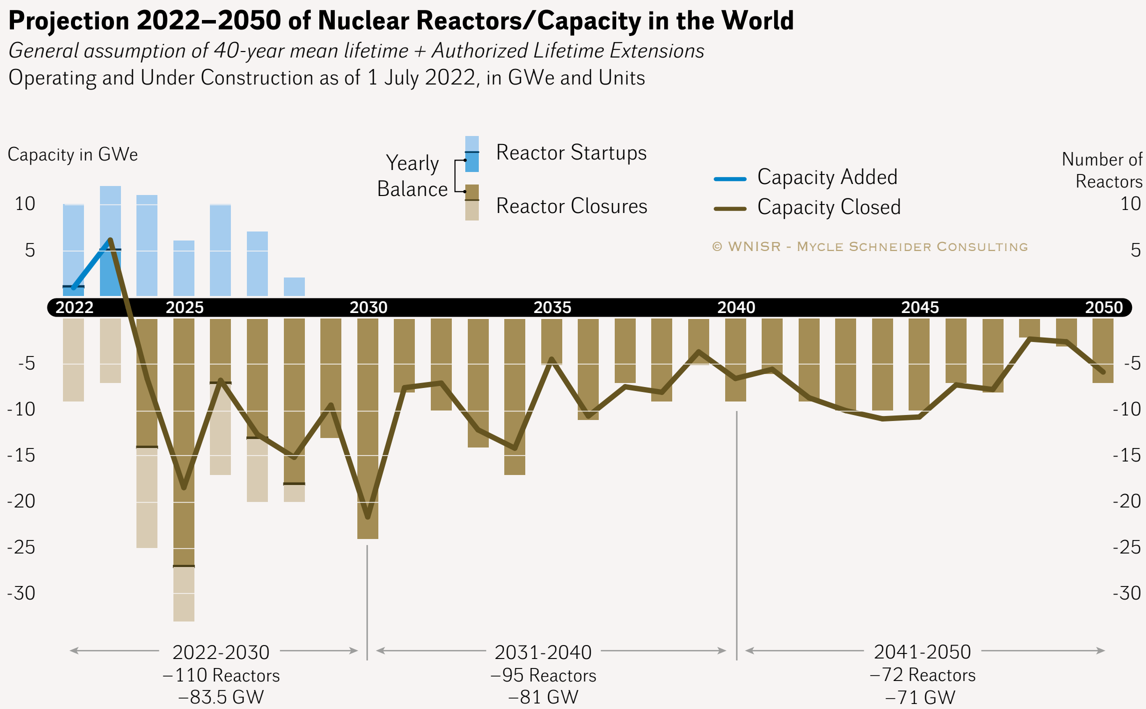
In the case of reactors that have reached 40 years of operation prior to 2022, the 40-year projection also uses the end of their licensed lifetime (including reactors licensed for 80 years in the U.S.).

In the case of French reactors that have reached 40 years of operation prior to 2022 (startup before 1982), 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 2022 (9 reactors), we use a 10-year extension, although no licensing procedure has been completed for this extension. 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.

The stabilization of the situation by the end of 2022 is only possible because most reactors will likely not close at the end of the year, regardless of their age. As a result, 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 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 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, Chinese medium-term ambitions appear significantly lower than anticipated in the pre-3/11 era.

Figure 20 · The PLEX Projection (not including LTOs)



Sources: Various sources, compiled by WNISR, 2022

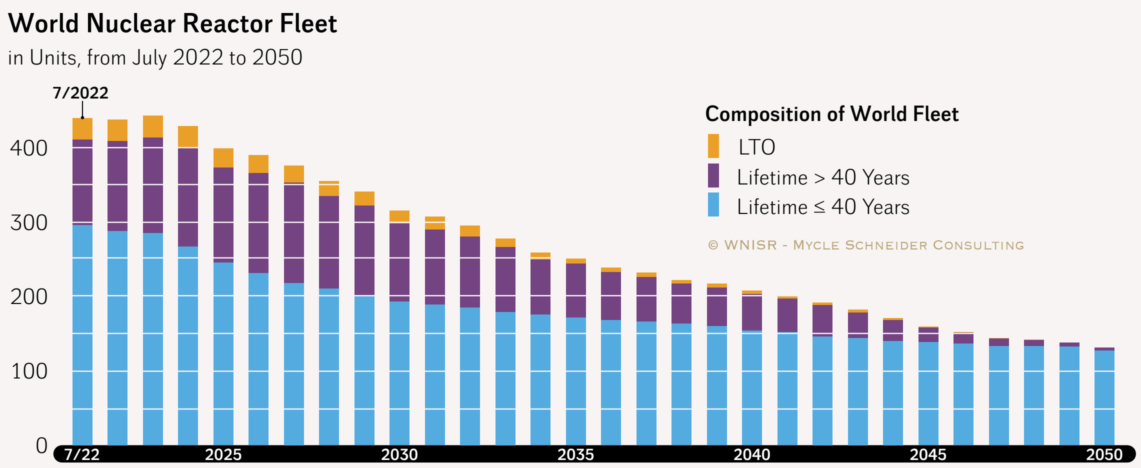
Notes: see Figure 19.

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 2022, the net number of operating reactors and operating capacity would remain almost stable (+ 1 unit / + 0.9 GW).

In the decade to 2030, the net balance would turn negative as soon as 2024, and an additional 110 new reactors (83.5 GW)—one unit or 0.7 GW per month—would have to start up or restart to replace closures. The PLEX-Projection would still mean, in the coming decade, a need to double the annual building rate of the past decade from six to twelve (see Figure 19, Figure 20 and the cumulated effect in Figure 21).

However, as has been documented construction starts have not been picking up over the past decade. Between 2012 and 2016, a total of 32 constructions were launched around the world, of which 16 in China and three later abandoned. Between 2017 and 2021, constructions started at 31 units, of which 15 in China, thus an average of six units per year were launched and sustained, significantly less than half than of the building rate needed according to the PLEX Projection over the coming decade just to maintain the current number of operating reactors in the world.

Figure 21 · Forty-Year Lifetime Projection versus PLEX Projection



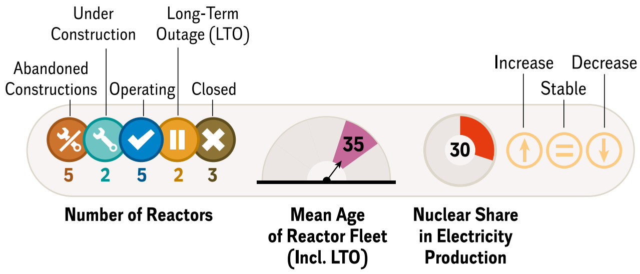
Sources: Various sources, compiled by WNISR, 2022

Note: 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 53 reactors under construction as of 1 July 2022. (See Figure 19.)

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.

FOCUS COUNTRIES

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



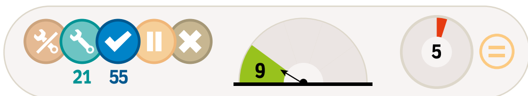
The following chapter offers an in-depth assessment of ten countries: China, Finland, France, Germany, India, Japan, South Korea, Taiwan, United Kingdom (U.K.), and the United States (U.S.). They represent 30 percent of the nuclear countries, two thirds of the global reactor fleet and four of the world's five largest nuclear power producers. For other countries' details, see Annex 1.

Unless otherwise noted, data on reactor capacity (as of mid-2022) and nuclear's share in electricity generation in 2021 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.

See Annex 2 for a general country overview of main indicators.

CHINA FOCUS



As of mid-2022, China had 55 operating reactors, including the China Experimental Fast Reactor (CEFR), with a combined capacity of around 52 GW. Nuclear plants generated 383.2 TWh in 2021, which constitutes 5 percent of the electricity produced in the country, almost the same as in 2020. In absolute terms, total electricity generated represents an increase of 11 percent over the 2020 value, which pales in comparison to increases of 40 percent and 25 percent increases in wind and solar energy generation respectively. Coal increased by about 9 percent.[42]

China operates by far the youngest large nuclear fleet in the world, with 41 reactors, almost four in five, having connected to the grid within the past ten years (see Figure 22).

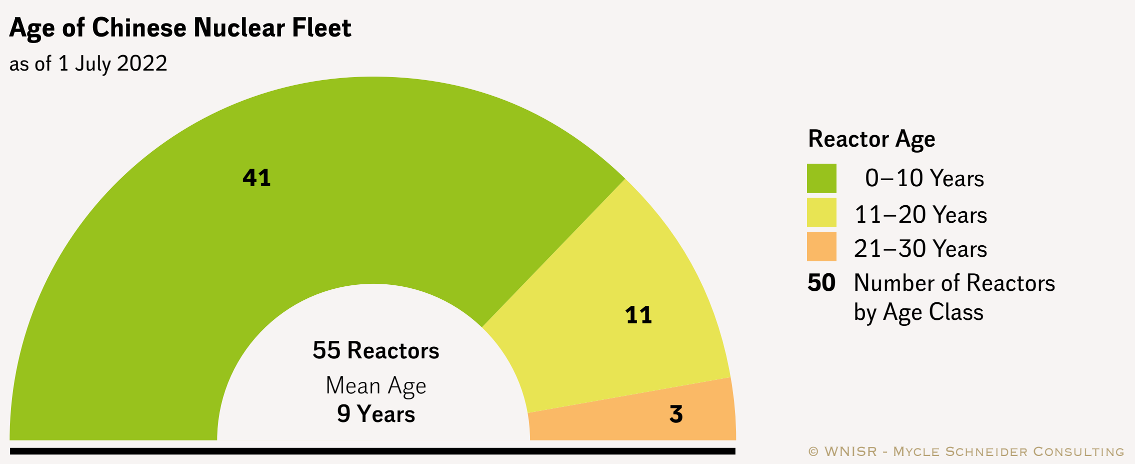
In March 2022, the National Energy Administration (NEA) issued the "14th Five-year Plan for Modern Energy System", which called for "the active development of nuclear power in a safe and orderly manner" and set the target of increasing installed nuclear power capacity to 70 GW by 2025.[43] The target laid out in the 2021–2025 five-year plan was also 70 GW. That

42 - China Energy Portal, "2021 electricity & other energy statistics (preliminary)", 27 January 2022, see https://chinaenergyportal.org/2021-electricity-other-energy-statistics-preliminary/, accessed 27 January 2022.

43 - *Global Times*, "China to expand deployment of nuclear power in clean, secure energy push", 22 March 2022, see https://www.globaltimes.cn/page/202203/1256556.shtml, accessed 10 April 2022.

target of 70 GW was first suggested for 2020 by the China Nuclear Energy Association more than a decade ago, in 2010, and there were even targets as large as 114 GW by 2020 that were reported at the time.[44]

Figure 22 · Age Distribution of Chinese Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2022

The relatively low target appears to reflect a continued caution about the growth of nuclear power, which became apparent in the aftermath of the multiple nuclear accidents at Fukushima.[45] Indeed, there were concerns about expanding nuclear power too rapidly even prior to those accidents. In 2009, Li Ganjie, then the director of China's National Nuclear Safety Administration, warned: "At the current stage, if we are not fully aware of the sector's over-rapid expansions, it will threaten construction quality and operation safety of nuclear power plants".[46]

In the end, the suggestion of 70 GW by 2020 was not accepted by the Chinese leadership. Instead, the target set for 2020 was to put "58 GW into operation and have another 30 GW under construction", and in 2016, the chairman of the China Atomic Energy Authority asserted that China was due to meet that target.[47] Those targets were not met; which will also be the case with the current target for 70 GW of operational capacity by the end of 2025. The combined net capacity of the operational plants and the ones under construction that are due to be operating before 2026 is only around 61 GW—and that is assuming no further delays. In other words, the goal of 70 GW at the end of 2025 is simply not achievable.

44 - David Stanway, "China nuclear body recommends 2020 target of 70 GW", *Reuters*, 24 November 2010, see https://www.reuters.com/article/china-nuclear-idUSBJI00247420101124, accessed 8 April 2022; and *Power Engineering*, "China raises 2020 nuclear target by 62 per cent to 114 GW", 3 December 2010, see https://www.power-eng.com/nuclear/china-raises-2020/, accessed 25 February 2017.

45 - Amy King and M.V. Ramana, "The China Syndrome? Nuclear Power Growth and Safety After Fukushima", *Asian Perspective*, Vol 39, No 4, *Johns Hopkins University Press*, October–December 2015.

46 - Keith Bradsher, "China's Rapid Reactor Expansion Raises Safety Concerns", *The New York Times*, 15 December 2009, see http://www.nytimes.com/2009/12/16/business/global/16chinanuke.html, accessed 28 December 2016.

47 - David Stanway, "China on course to meet 2020 nuclear capacity targets -official", *Reuters*, 27 January 2016, see https://www.reuters.com/article/china-nuclear-idUSL3N15B299, accessed 24 April 2022.

The NEA's plan also set a 2025 target of 39 percent for the share of electricity generated from non-fossil fuels, as compared to 32.6 percent in 2021. But much of this increase is expected to come from renewables. In October 2021, China's Nationally Determined Contribution report (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) set a target of 1,200 GW by 2030 for total installed capacity of wind and solar power, but media reports and expert analyses of projects already being planned suggest that this target could even be met by 2025.[48]

As of June 2022, there was a total of 340 GW of solar PV reportedly installed in the country.[49] About half of the wind and solar capacity to be connected to the grid by 2025 is expected to be from gigantic clean energy bases.[50] Further, the NEA's March 2022 plan requires "200 GW of coal-fired generation to be retrofitted to enhance flexibility, especially small units below 300 MW, which allows them to be restarted at short notice to back up solar and wind capacity, to resolve intermittency issues".[51] The Chinese government is evidently trying to resolve the widely acknowledged challenge for solar and wind power projects of their outputs being curtailed during periods of high production and/or low demand.[52] Curtailment has declined in recent years,[53] but there is still concern that it will increase as renewable energy becomes a larger fraction of the supply of electricity.

The ongoing anticorruption campaign might also have some effect on the pace of growth of nuclear power. In March 2022, Liu Baohua, NEA deputy director, was sentenced to 13 years in prison for taking bribes.[54] Since the launch of the anti-corruption campaign, numerous officials—from central to local energy system representatives, from regulatory agencies to large power generation institutions—have been investigated for corruption. According to a listing from October 2020 in *Nuclear Intelligence Weekly*, there had been at least eleven other indictments of senior NEA officials in the previous eight years.[55]

48 - Ivy Yin and Oceana Zhou, "China to raise share of non-fossil fuels in electricity supply to 39% by 2025", *S&P Global*, 23 March 2022, see https://www.spglobal.com/commodity-insights/en/market-insights/latest-news/energy-transition/032322-china-to-raise-share-of-non-fossil-fuels-in-electricity-supply-to-39-by-2025, accessed 8 April 2022; and *Bloomberg*, "China Could Hit 2030 Renewable Target by 2025 on Local Ambitions", 24 March 2022, see https://www.bloomberg.com/news/articles/2022-03-25/china-could-hit-2030-renewable-target-by-2025-on-local-ambitions, accessed 8 April 2022; also Lauri Myllyvirta and Xing Zhang, "Analysis: What do China's gigantic wind and solar bases mean for its climate goals?", *Carbon Brief*, 3 May 2022, see https://www.carbonbrief.org/analysis-what-do-chinas-gigantic-wind-and-solar-bases-mean-for-its-climate-goals, accessed 3 May 2022.

49 - Vincent Shaw, "China may install up to 100 GW of solar this year", *PV Magazine International*, 22 July 2022, see https://www.pv-magazine.com/2022/07/22/chinese-pv-industry-brief-china-may-install-up-to-100-gw-of-solar-this-year, accessed 22 July 2022.

50 - Lauri Myllyvirta and Xing Zhang, "Analysis: What do China's gigantic wind and solar bases mean for its climate goals?", 2022, op. cit.

51 - Ivy Yin and Oceana Zhou, "China to raise share of non-fossil fuels in electricity supply to 39% by 2025", *S&P Global*, 2022, op. cit.

52 - Emily Feng, "China wants to go carbon neutral, but has no way to forcibly end its reliance on coal", *NPR*, 1 October 2021, see https://www.npr.org/2021/10/01/1041266538/china-wants-to-go-carbon-neutral-but-has-no-way-to-forcibly-end-its-reliance-on-, accessed 16 April 2022.

53 - Xian Zhang et al., "What is driving the remarkable decline of wind and solar power curtailment in China? Evidence from China and four typical provinces", Renewable Energy, Volume 174, August 2021; and Hao Chen, Jiachuan Chen et al., "Winding down the wind power curtailment in China: What made the difference?", *Renewable and Sustainable Energy Reviews*, Vol. 167, October 2022.

54 - *The BL*, "China's energy department former top official punished 13 years in jail for taking $11M in bribes", Spotlight on China, 18 March 2022, see https://thebl.tv/video/chinas-energy-department-former-top-official-punished-13-years-in-jail-for-taking-11m-in-bribes, accessed 8 April 2022.

55 - C.F. Yu, "Top NEA Nuclear Official Indicted on Corruption Charges", *Nuclear Intelligence Weekly*, 30 October 2020.

Since the release of WNISR2021, only three units have been connected to the grid: Fuquing-6, Shidao Bay 1-1 and Honghyane-6. Fuqing-6, a Hualong 1 unit, was connected to the grid in January 2022, a little over six years after construction started in December 2015.[56]

The first of two High Temperature Gas Cooled Reactor (HTGR) units at Shidao Bay (Shidao Bay 1-1 and 1-2)—IAEA-PRIS considers these as one plant—was connected to the grid on 20 December 2021.[57] As of the time of this writing, there is no public announcement that the second unit has been connected. Further, between January and June 2022, there was no power fed to the grid from this site, according to China Nuclear Energy Industry Association (CNEIA).[58] No information has been published about the reasons for the additional delays in commissioning the second unit and for the shutdown of the first unit in the first half-year of 2022. CNEIA also records no power fed into the grid from Taishan-1 during the same period.

"Actually, construction took nearly 109 months, more than twice the expected length."

Construction of the Shidao Bay HTGR reactors started in December 2012 and at that time construction was projected to "take 50 months, with 18 months for building, 18 months for installation and 14 months for pre commissioning".[59] Actually, construction took nearly 109 months, more than twice the expected length. In addition to the lengthy delay, another problem for these HTGR units is high capital cost. The World Nuclear Association (WNA) reported a construction cost of US$6,000 per kW for these units as compared to figures in the range of US$2,600 to US$3,500 per kW for Hualong-One reactors.[60] Further, the costs for fuel fabrication, operations, and maintenance would be thrice the corresponding costs for light water reactors.[61]

When construction of Hongyanhe-6 started in 2015, it was scheduled to begin operating in 2020.[62] In March 2022, China General Nuclear (CGN) announced that fuel loading had been completed[63] and the reactor was finally connected to the grid on 2 May 2022.[64]

56 - *WNN*, "Fuqing 6 reaches full power as Hongyanhe 6 nears startup", 21 February 2022, see https://www.world-nuclear-news.org/Articles/Fuqing-6-reaches-full-power-as-Hongyanhe-6-nears-s, accessed 20 April 2022; and *WNN*, "First concrete for sixth Fuqing unit", 22 December 2015, see http://www.world-nuclear-news.org/NN-First-concrete-for-sixth-Fuqing-unit-2212154.html, accessed 16 June 2019.

57 - WNISR, "Grid Connection for First High-Temperature Reactor Module in China", World Nuclear Industry Status Report, 24 December 2021, see https://www.worldnuclearreport.org/Grid-Connection-for-First-High-Temperature-Reactor-Module-in-China.html, accessed 17 April 2022.

58 - Department of Nuclear Power Evaluation, "《全国核电运行情况（2022年1-6月）》" ["National Nuclear Power Operation (January-June 2022)"], China Nuclear Energy Industry Association, 29 July 2022, see https://www.china-nea.cn/site/content/41232.html, accessed 26 August 2022.

59 - 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 9 January 2013.

60 - WNA, "Nuclear Power in China", World Nuclear Association, February 2022, see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx, accessed 28 February 2022.

61 - Edwin Lyman, "'Advanced' Isn't Always Better – Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors", Union of Concerned Scientists, March 2021, see https://www.ucsusa.org/resources/advanced-isnt-always-better.

62 - *WNN*, "Grid connection for Hongyanhe 4", 1 April 2016, see https://www.world-nuclear-news.org/NN-Grid-connection-for-Hongyanhe-4-0104164.html, accessed 27 May 2020.

63 - *WNN*, "Fuel loading completed at Hongyanhe 6", 28 March 2022, see https://www.world-nuclear-news.org/Articles/Fuel-loading-completed-at-Hongyanhe-6, accessed 5 April 2022.

64 - WNISR, "Startup of Hongyanhe-6 Nuclear Reactor in China", 6 May 2022, see https://www.worldnuclearreport.org/Startup-of-Hongyanhe-6-Nuclear-Reactor-in-China.html, accessed 31 August 2022.

As of 1 July 2022, there were 21 nuclear units under construction, including the Xiapu fast reactor units and the second HTGR unit at Shidao Bay 1. The projects that are currently under construction include Fangchenggang-3 since 2015, Fangchenggang-4 since 2016, four reactors (Zhangzhou-1, Taipingling-1, Shidao Bay 2-1 and Shidao Bay 2-2) since 2019; three units (Taipingling-2, Sanaocun-1, Zhangzhou-2) since 2020, and three more (Changjiang-3, Tianwan-7, and Xudabao-3) since the first half of 2021.[65]

Since mid-2021, construction has started on six reactors (Changjiang SMR, Changjiang-4, Sanaocun-2, Tianwan-8, Xudabao-4, and Sanmen-3).[66] Two of these are reactors supplied by Russia's Rosatom with construction starting after the commencement of the war on Ukraine. There are no official dates for the construction start of the Xiapu fast reactor units, but construction of the first unit is reported to have started in 2017 and the second unit in 2021.[67]

The startup of at least two reactors currently under construction has been significantly delayed. The first of the Fangchenggang units was scheduled to start trial operations in 2020.[68] In January 2022, CGN adjusted the expected date of commencement of operation of Fangchenggang-3 to the second half of 2022, and Fangchenggang-4 to the first half of 2024.[69] These units were to be the reference for the proposed Bradwell B project in the U.K.[70]

China has ambitions to export nuclear power plants. Chinese officials promote this aim with the justification that it will encourage industrial production, especially of highly sophisticated equipment. In 2016, the president of China National Nuclear Corporation (CNNC) announced that "China aims to build 30 overseas nuclear power units… by 2030".[71] So far China has only exported nuclear plants to Pakistan. All six units operating in Pakistan are of Chinese

65 - *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; 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 and WNA, "Nuclear Power in China", February 2022, op. cit.

66 - WNISR, "Construction Start of Changjiang-4 and Sanaocun-2 Reactors in China", World Nuclear Industry Status Report, 10 January 2022, see https://www.worldnuclearreport.org/Construction-Start-of-Changjiang-4-and-Sanaocun-2-Reactors-in-China.html, accessed 24 April 2022; Rosatom, "Yet Another First Concrete", Rosatom Newsletter, March 2022, see https://rosatomnewsletter.com/2022/03/27/yet-another-first-concrete/, accessed 24 April 2022; and *WNN*, "Construction begins at second Changjiang Hualong One", 29 December 2021, see https://world-nuclear-news.org/Articles/Construction-begins-at-second-Changjiang-Hualong-O, accessed 30 December 2021; and *WNN*, "China starts construction of demonstration SMR", 13 July 2021, see https://www.world-nuclear-news.org/Articles/China-starts-construction-of-demonstration-SMR, accessed 15 July 2021; also WNISR, "Third Nuclear Reactor Construction Start in China in 2022 - As of mid-year, no new-build launched yet in any other country", 29 June 2022, see https://www.worldnuclearreport.org/Third-Nuclear-Reactor-Construction-Start-in-China-in-2022.html, accessed 29 June 2022. Construction of one reactor started since 1 July 2022, see WNISR, "Nuclear Construction Starts 2022: China 4, Rest of the World 0", 15 July 2022, see https://www.worldnuclearreport.org/Nuclear-Construction-Starts-2022-China-4-Rest-of-the-World-0.html, accessed 24 July 2022.

67 - *WNN*, "China begins building pilot fast reactor", 29 December 2017, see http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html, accessed 16 June 2019; *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.

68 - *NEI Magazine*, "China to build more Hualong One reactors", *Nuclear Engineering International*, 25 February 2016, see http://www.neimagazine.com/news/newschina-to-build-more-hualong-one-reactors-4821665, accessed 17 June 2016.

69 - CGN, "Inside Information Construction Progress of Fangchenggang Units 3 and 4", CGN Power Co., 26 January 2022, see http://en.cgnp.com.cn/encgnp/c211222/2022-01/26/4197b03727be4723a8240db19375c3fc/files/cd02f04566144542ab87ed85fa32f35d.pdf, accessed 31 January 2022.

70 - *WNN, "Approval for four new Chinese reactors", World Nuclear News, 17 December 2015.*

71 - Xinhua, "China plans 30 overseas nuclear power units by 2030", as published by the Ministry of Foreign Affairs of the People's Republic of China, 1 March 2016, see https://www.mfa.gov.cn/ce/cgny//eng/xw/t1344453.htm, accessed 31 August 2022.

design. Various other international projects, including in Romania and the U.K., have so far not proceeded to the stage of construction.

In February 2022, CNNC signed an agreement to build a Hualong One nuclear plant in Argentina.[72] How this project will evolve is uncertain. Argentina has signed many agreements earlier, including one between Nucleoelectrica Argentina SA, Atomic Energy of Canada Ltd, and CNNC in 2007 to construct a CANDU reactor.[73] Again, in 2017, Chinese president Xi Jinping and Argentinean president Mauricio Macri signed an agreement with China to build a CANDU and a Hualong One reactor.[74] Neither of these happened.

"Solar power generated the equivalent of more than 80 percent of nuclear electricity whereas wind power exceeded nuclear generation by 60 percent."

In the case of the latter agreement, the requirement reportedly hinged "entirely on the Chinese side putting up the financing".[75] This time too, the Argentinian government is pushing China to fully finance construction of this plant because it is dealing with high debt levels.[76] Whether China can come up with this financing—on top of all the other Belt and Road Initiative construction projects—remains an open question.[77]

In the meantime, renewable energy capacity in China continues to grow rapidly. According to the China Electric Power Industry Association, total installed renewable capacity increased by 13.4 percent in the past year, going from 905 GW in 2020 to 1,026 GW in 2021. The largest component of that expansion was in solar capacity, which increased from 253 GW in 2020 to 306 GW in 2021; wind capacity went from 281 GW in 2020 to 328 GW in 2021.[78] Wind and solar power injected respectively 656 TWh and 327 TWh to the grid in 2021; solar power generated the equivalent of more than 80 percent of nuclear electricity whereas wind power exceeded nuclear generation by 60 percent.[79]

72 - *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.

73 - *WNN*, "Canada, Argentina and China to cooperate on Candu projects", *World Nuclear News*, 5 September 2007, see https://world-nuclear-news.org/Articles/Canada,-Argentina-and-China-to-cooperate-on-Candu, accessed 17 April 2022.

74 - *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.

75 - Charles Newbery and Gao Fu Mao, "Argentina-China talks on new nuclear plants", *WNN*, 8 May 2015, see http://www.world-nuclear-news.org/NN-Argentina-China-talks-on-new-nuclear-plants-08051501.html, accessed 7 May 2018.

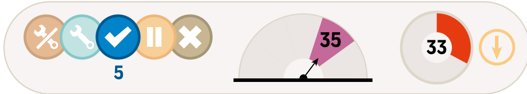
76 - Eliana Raszewski, "Argentina wants China to fully fund $8.3 bln nuclear plant amid cash shortfall", *Reuters*, 5 April 2022, see https://www.reuters.com/business/energy/argentina-wants-china-fully-fund-83-bln-nuclear-plant-amid-cash-shortfall-2022-04-05/, accessed 6 April 2022.

77 - M.V. Ramana, "Even China Cannot Rescue Nuclear Power from its Woes", Center for Asian Studies, University of Colorado, 12 April 2022, see https://www.colorado.edu/cas/2022/04/12/even-china-cannot-rescue-nuclear-power-its-woes, accessed 13 April 2022.

78 - China Electric Power Industry Association, "2021年全国电力工业统计快报一览表" ["2021 National Electricity Industry Statistical Snapshot List"], 2022 (in Chinese), see https://www.cec.org.cn/upload/1/editor/1642758964482.pdf, accessed 24 April 2022.

79 - China Energy Portal, "2021 electricity & other energy statistics (preliminary)", 27 January 2022, op. cit.

FINLAND FOCUS



Four nuclear reactors supplied 22.7 TWh of electricity in Finland, close to the peak 22.9 TWh in 2019. The nuclear share represented 32.8 percent in 2021, a drop of 1.1 percentage points over 2020, compared to a peak of 38.4 percent in 1986.

Finland's fifth reactor, the 1.6 GW 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.[80] Credit-rating agencies welcomed the development and raised TVO's rating based on then scheduled commercial operation by July 2022.[81]

Following the pattern of countless technical problems and delays during the construction phase, the commissioning stage of OL3 continues 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 is to start in December 2022, instead of the previously announced start in September 2022".[82] In mid-2020, the schedule was still for commercial operation to begin by 31 May 2021,[83] but progressively delayed to July, then September, then December 2022. Even after first grid connection, technical issues keep impacting the startup schedule.

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 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 43.3 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.[84] On 20 September 2018, the Cabinet approved the lifetime extension for both units to operate until 2038.[85]

In March 2022, Fortum, owner-operator of the Loviisa nuclear power plant, filed a license renewal application with the Finnish government aiming at a permission to operate the two

80 - WNISR, "Europe's First EPR: 13 Years Behind Schedule, Olkiluoto-3 in Finland Starts Up", 25 March 2022, see https://www.worldnuclearreport.org/Europe-s-First-EPR-13-Years-Behind-Schedule-Olkiluoto-3-in-Finland-Starts-Up.html, accessed 22 August 2022.

81 - Ratings remain in non-investment / speculative grade ("junk") though. E.g. Standard & Poor's raised TVO's rating from BB to BB+; Standard & Poor's, "Finnish Nuclear Producer Teollisuuden Voima Upgraded To 'BB+' From 'BB' On OL3 Plant's Startup; Outlook Positive", 21 March 2022.

82 - TVO, "TVO - Olkiluoto 3 EPR's test production will continue in the end of July", 15 June 2022, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2022/olkiluoto3epr8217stestproductionwillcontinueintheendofjuly.html, accessed 22 August 2022.

83 - TVO, "The terms of the OL3 EPR project completion have been agreed", 17 May 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/thetermsoftheol3eprprojectcompletionhavebeenagreed.html, accessed 13 July 2021.

84 - 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 13 July 2021.

85 - TVO, "Finnish Government Approves Extension of Operating Licences For OL1 And OL2 Plant Units", Press Release, 20 September 2018, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2018/h7tODvf1I.html, accessed 13 July 2021.

units until the end of 2050.[86] Current licenses had already been extended in 2007 and expire in 2027 and 2030 respectively.[87] 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. Fortum estimates that the application review process will take about one year.

Fennovoima's Hanhikivi Project Cancelled

In 2007, the group Fennovoima was set up as a non-profit cooperative of power companies and industry.[88] 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,[89] and then in April 2014 a "binding decision to construct" Hanhikivi-1, a 1,200 MW AES-2006 reactor, was announced.[90]

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.[91] Construction of Hanhikivi-1 was then ten years behind the original schedule.[92] Estimated costs for the project had increased from €6.5-7 billion (US$7.7–8.3 billion) to €7–7.5 billion (US$8.3–8.8 billion).[93]

In November 2021, the Finnish Ministry of Defense included a quite premonitory request into a security risk analysis of the Hanhikivi Project that "should include a clear look at, for example, how any new sanctions on Russia would affect the project and how they would be treated. Account should also be taken of the Rosatom Group's links with the Russian defense industrial complex and related measures to pursue Russia's security policy goals."[94]

Three months later, Russia invaded Ukraine, which dramatically changed the situation of the Hanhikivi project. Four days after the invasion started, Fennovoima declared that "for the time being, we continue executing our project and carefully follow the developments of the situation",[95] and on 15 March 2022 added that, while the nuclear sector has not been explicitly included, "the current decided sanctions are expected to impact the Hanhikivi 1 project. Fennovoima considers the situation to be challenging."[96]

86 - 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.

87 - Ministry of Economic Affairs and Employment, "Operating licences of Loviisa 1 and 2 expire in 2027 and 2030", Government of Finland, Undated, see https://tem.fi/en/loviisa-1-and-2-operating-licence, accessed 27 April 2022.

88 - *Modern Power Systems*, "Clearing the Way for Finland's Next Nuclear Power Plant", 26 March 2018, see https://www.modernpowersystems.com/features/featureclearing-the-way-for-finlands-next-nuclear-power-plant-6094892/, accessed 21 August 2022.

89 - Fennovoima, "Rosatom Acquired 34% of Fennovoima", Press Release, 27 March 2014.

90 - 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 29 August 2022.

91 - Fennovoima, "Fennovoima Updates the Construction License Application", Press Release, 28 April 2021.

92 - *NEI*, "Fennovoima Issues Progress Report on Hanhikivi" 26 March 2020, see https://www.neimagazine.com/news/newsfennovoima-issues-progress-report-on-hanhikivi-7839412, accessed 13 July 2021.

93 - Fennovoima, "Fennovoima Updates the Construction License Application", 28 April 2021, op. cit.

94 - Ariane Sains, "Finnish Energy Ministry Considers Fennovoima Review on Security Grounds", *Nucleonics Week*, 10 November 2021.

95 - Fennovoima, "Fennovoima's updated statement on the situation in Ukraine", 28 February 2022.

96 - Fennovoima, "Fennovoima's statement on 15.3. on the situation in Ukraine", 15 March 2022.

The Finnish city of Vantaa was the first Fennovoima shareholder to publicly state, on 28 March 2022, that its municipal energy company, Vantaan Energia, would have to withdraw from the Hanhikivi project, saying the situation in Ukraine "makes it unlikely a license would be granted".[97]

On 4 April 2022—one month after Russian forces attacked and then occupied the Zaporizhzhia nuclear plant in Ukraine—Fennovoima reiterated the statement that "for the time being, we continue executing our project and carefully follow the developments of the situation".[98] One week later, Rosatom's subsidiary RAOS Project told *Reuters:* "Rosatom and RAOS Project continue fulfilling their obligations under signed agreements and contracts relating to the Hanhikivi 1 project".[99]

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".[100] The reasons indicated in a press statement were

> …RAOS Project's significant delays and inability to deliver the project. There have been significant and growing delays during the last years. The war in Ukraine has worsened the risks for the project. RAOS has been unable to mitigate any of the risks.[101]

Rosatom immediately replied that the decision to cancel the contract "was taken without any detailed consultation with the project's shareholders, the largest of which is RAOS Voima" and that "the reasons behind this decision are completely inexplicable to us."[102] On 6 May 2022, Rosatom issued a further statement saying that "the arguments presented by our Finnish partners for the termination contradict the actual status of the project and Fennovoima's earlier statements noting the progress and prospects for its successful completion". Rosatom concluded that "the decision of the Finnish partners to terminate the Hanhikivi-1 NPP project is non-market and politically motivated" and thus "we have no other choice but to defend ourselves and demand compensation for this unlawful termination".[103]

On 24 May 2022, Fennovoima has officially withdrawn the Hanhikivi-1 license application.[104]

97 - *NEI Magazine*, "Finnish city seeks to sell stake in Hanhikivi project", *Nuclear Engineering International*, 31 March 2022, see https://www.neimagazine.com/news/newsfinnish-city-seeks-to-sell-stake-in-hanhikivi-project-9591791, accessed 3 April 2022.

98 - Fennovoima, "Fennovoima's update on the impacts of war in Ukraine 4.4.", 4 April 2022.

99 - Anne Kauranen, "Rosatom Subsidiary Will Proceed With Finnish Nuclear Project", *Reuters*, 11 April 2022, see https://www.reuters.com/business/energy/rosatom-subsidiary-will-proceed-with-finnish-nuclear-project-2022-04-11/, accessed 29 August 2022.

100 - Fennovoima, "Fennovoima has terminated the contract for the delivery of the Hanhikivi 1 nuclear power plant with Rosatom", 2 May 2022, see https://www.fennovoima.fi/en/press-releases/fennovoima-has-terminated-contract-delivery-hanhikivi-1-nuclear-power-plant-rosatom, accessed 2 May 2022.

101 - Fennovoima, "Fennovoima has terminated the contract for the delivery of the Hanhikivi 1 nuclear power plant with Rosatom", 2 May 2022, see https://www.fennovoima.fi/en/press-releases/fennovoima-has-terminated-contract-delivery-hanhikivi-1-nuclear-power-plant-rosatom, accessed 2 May 2022.

102 - Rosatom, "ROSATOM statement on the Hanhikivi 1 NPP project", 2 May 2022, see https://www.rosatom.ru/en/press-centre/news/rosatom-statement-on-the-hanhikivi-1-npp-project/, accessed 2 May 2022.

103 - Rosatom-RAOS Project, "We Consider Fennovoima's Reasons For Terminating The Hanhikivi 1 Delivery Contract Unfounded", 6 May 2022, see https://raosproject.fi/news/we-consider-fennovoima-s-reasons-for-terminating-the-hanhikivi-1-delivery-contract-unfounded/, accessed 10 May 2022.

104 - Hanhikivi 1, "Fennovoima has withdrawn the Hanhikivi 1 Construction License Application – focus is now on preserving the Pyhäjoki site", 24 May 2022.

In 2018, it was reported that Fennovoima would invest €400–500 million (US$$_{2018}$494–618 million) into the project *before the construction even started*.[105] When announcing the contract cancellation, Fennovoima's Board Chairman, Esa Harmala, told reporters the consortium had already spent €600-700 million (US$$_{2022}$600–700 million) on the project.[106]

The contract cancellation will no doubt lead to a lengthy legal battle between stakeholders.

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 by Siemens, was contracted to build the European Pressurized Reactor (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.[107] 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.

"OL3 construction started in August 2005, with operations planned from 2009. However, that date—and other dates—passed."

However, EDF made it clear that it would not take over the billions of euros' liabilities linked to the costly Finnish AREVA adventure.[108] Thus, it was decided that the financial liability for OL3 and associated risks stay with AREVA S.A. after the sale of AREVA NP and the creation of a new company AREVA Holding, now named Orano, that will focus on nuclear fuel and waste management services, very similar to the old COGEMA. In July 2017, the French Government confirmed that it had completed its €2 billion (US$$_{2018}$2.3 billion) capital increase,[109] most of which was to cover some of the costs to AREVA of the OL3 investment.

The OL3 project was financed essentially on the balance sheets of the Finland's leading firms and heavy energy users as well as several municipalities under a unique arrangement that makes them liable for the plant's indefinite capital costs for an indefinite period, whether or not they get the electricity—a capex "take-or-pay contract"—in addition to the additional billions incurred by AREVA under the fixed price contract.

OL3 construction started in August 2005, with operations planned from 2009. However, that date—and other dates—passed.

105 - Modern Power Systems, "Clearing the Way for Finland's next Nuclear Power Plant", March 2018, op. cit.

106 - Anne Kauranen and Essi Leht, "Finnish group ditches Russian-built nuclear plant plan", *Reuters*, 2 May 2022, see https://www.reuters.com/world/europe/finnish-group-ditches-russian-built-nuclear-plant-plan-2022-05-02/, accessed 3 May 2022.

107 - *WNN*, "Siemens quits the nuclear game", 19 September 2011, see https://www.world-nuclear-news.org/Articles/Siemens-quits-the-nuclear-game, accessed 29 August 2022.

108 - Jean-Michel Bezat, "EDF pose ses conditions au rachat des réacteurs d'Areva" ["EDF names its terms for the purchase of Areva's reactors"], *Le Monde*, 19 May 2015.

109 - Jean-Michel Belot and Richard Lough, "Areva says French state completes two billion-euro capital increase", *Reuters*, 12 July 2017, see https://www.reuters.com/article/us-arevasa-capital-idUSKBN19X2S9, accessed 13 July 2021.

From the beginning, the OL3 project was plagued with countless management and quality-control issues. Not only did it prove difficult to carry out concreting and welding to technical specifications, but the use of sub-contractors and workers from over 50 nationalities made communication and oversight extremely complex (see previous WNISR editions).

After further multiple delays, TVO announced in June 2018 that grid connection was planned for May 2019 and "regular electricity generation" in September 2019.[110] In April 2019, fuel loading was pushed further to August 2019. TVO's plans for grid connection in October 2019 and electricity generation by January 2020[111] were considered by WNISR2019 as highly optimistic

In July 2019, TVO announced that it had once again delayed operations for OL3 by six months.[112] The startup date was moved to July 2020 by nuclear plant supplier the AREVA-Siemens consortium. TVO announced that nuclear fuel was scheduled to be loaded into the reactor in January 2020 and the first connection to the grid was to be in April 2020. By November 2019, the revised schedule for OL3 start had slipped a further six weeks, according to TVO.[113] The delays were said to be due to final verification of the mechanical, electrical and Instrumentation and Control (I&C) systems.

In December 2019, the AREVA-Siemens Consortium informed TVO[114] that OL3 would be connected to the grid in November 2020 with regular electricity generation from March 2021.[115] Nuclear fuel loading was planned for June 2020. The delays were said to be due to "slow progress of system tests and shortcomings in spare-part deliveries".[116] Among other things, in the tests of auxiliary diesel generators some faulty components were found.[117]

On 8 April 2020, TVO announced that it had applied to the regulator STUK, for approval for fuel loading.[118] It was expected to take two months. At the same time, TVO revealed that "a significant amount of measures [were] taken to prevent the spreading of the coronavirus epidemic (COVID-19) in order to minimize the effects of pandemic risk to the project. The coronavirus pandemic may have significantly added uncertainty to the progress of the

110 - TVO, "OL3 EPR's regular electricity generation starts in September 2019", Press Release, 13 June 2018, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2018/hAZ2olOtQ.html, accessed 13 July 2021.

111 - *WNN*, "TVO starts work to resolve Olkiluoto 3 vibration issue", 23 May 2019, see https://www.world-nuclear-news.org/Articles/TVO-starts-work-to-resolve-Olkiluoto-3-vibration-i, accessed 13 July 2021.

112 - TVO, "OL3 EPR's regular electricity generation starts in July 2020", 17 July 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2019/h3BCeyaya.html, accessed 13 July 2021.

113 - TVO, "Plant supplier updates the schedule of OL3 project", Press Release, 8 November 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2019/hoaOkf1fA.html, accessed 13 July 2021.

114 - *YLE*, "Olkiluoto 3 reactor delayed yet again, now 12 years behind schedule", 20 December 2019, see https://yle.fi/uutiset/osasto/news/olkiluoto_3_reactor_delayed_yet_again_now_12_years_behind_schedule/11128489, accessed 13 July 2021.

115 - TVO, "OL3 EPR's regular electricity generation starts in March 2021", Press Release, 19 December 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprsregularelectricitygenerationstartsinmarch2021.html, accessed 13 July 2021.

116 - Ibidem.

117 - *YLE*, "Olkiluoto 3 reactor delayed yet again, now 12 years behind schedule", 20 December 2019, see https://yle.fi/uutiset/osasto/news/olkiluoto_3_reactor_delayed_yet_again_now_12_years_behind_schedule/11128489, accessed 13 July 2021.

118 - TVO, "TVO has submitted OL3 EPR unit nuclear fuel loading permission application", Press Release, 8 April 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/tvohassubmittedol3eprunitnuclearfuelloadingpermissionapplication.html, accessed 13 July 2021.

project."[119] As a consequence, fuel loading would not take place in June 2020 as planned, and "it is possible that the regular electricity production will be delayed respectively. AREVA-Siemens consortium will update the schedule for OL3 EPR unit as soon as spreading and effects of the coronavirus pandemic are known."[120]

As reported by WNISR2019 (see WNISR2019 Finland Focus), TVO and AREVA-Siemens signed a settlement agreement in March 2018, which states that TVO would receive compensation of €450 million (US$$_{2018}$549 million) from the supplier consortium. The settlement further includes a penalty mechanism, under which the supplier consortium pays additional penalties to TVO in case of further delays beyond 2019. However, these are capped at €400 million (US$458 million), which were reached in June 2021. With delays beyond June 2021, the agreement does not cover the financial impact on TVO. It was reported in April 2020, that AREVA was making arrangements to secure funding until the end of the project (including the guarantee period).[121]

In March 2021, fuel was finally loaded into the OL3 reactor, with grid connection announced in mid-May 2021 for October 2021.[122] By the end of July 2021, startup had already been pushed back by another month to November 2021, "due to turbine overhaul".[123]

On 17 May 2021, TVO announced that it had reached a consensus settlement agreement with the Areva–Siemens consortium.[124] 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. The deadline was missed once again. Further financial arrangements have not been communicated.

119 - Ibidem.

120 - Ibidem.

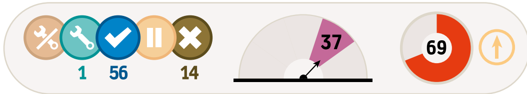
121 - Ibidem; and TVO, "OL3 EPR's schedule work continues", Press Release, 2 July 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprsscheduleworkcontinues.html, accessed 13 July 2021.

122 - TVO, "The terms of the OL3 EPR project completion have been agreed", Press Release, 17 May 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/thetermsoftheol3eprprojectcompletionhavebeenagreed.html, accessed 22 August 2021.

123 - 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 22 August 2021.

124 - *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 13 July 2021.

FRANCE FOCUS



Introduction

As documented in WNISR2021, 2020 was considered "particularly difficult for the French nuclear sector", but 2022 is likely to be significantly worse. While nuclear production increased over the previous year, the discovery in December 2021 of cracks in emergency core cooling systems led to the shutdown of the four largest (1,450 MW) and most recent French reactors. The event represented an unexpected loss of close to 6 GW of capacity in the middle of the winter when consumption peaks in France, more than in any other European country, due to about a third of the buildings using direct-resistance electric space heating. Subsequently, it turned out that certain 1300-MW reactors—there are 20 such units—are also showing similar symptoms and, as of mid-2022, 12 reactors are shut down for an unknown period of time due to the problem. To what extent the issue also concerns the 900 MW reactors—32 units—is yet to be seen.

Inspection techniques providing reliable results are a challenge in itself. 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".[125] If defaults are detected, it takes time to fabricate replacement parts, and it takes time to do the replacement work. High profile, experienced nuclear welders are rare—there are many more simultaneous challenges 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. As there have been already cases with several cracked piping pieces need to be replaced per reactor, inspection and repair will take time. EDF intends to inspect the entire fleet of 56 reactors only by 2025.

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 expected—120 TWh instead of 100 TWh—to limit the effect of sky-rocketing market prices for the consumer… and to keep potential voters happy prior to the April 2022 Presidential and June 2022 National Assembly elections. These measures were intended to limit the price increase, especially for companies and communities where regulated electricity rates (capped at 4 percent VAT) are not applied. However, rates will have to catch up in 2023.

The day following EDF's announcement of lower production expectations and the government-decided consumer subsidy, the company's shares plunged by 15 percent, and on 17 January 2022, credit-rating agency Standard & Poor's put EDF on credit watch negative, on the basis that they considered the combined effect of these developments could cut EDF's 2022 result by €10–13 billion (US$$_{2022}$11.4–14.8 billion).[126]

125 - 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.

126 - S&P Global, "Electricité de France Placed On CreditWatch Negative On Nuclear Outages And Adverse Political Decisions", Research Update, 17 January 2022, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/investors-analysts/credits/rating/sp-research-update-2022-01-17.pdf, accessed 30 August 2022.

This latest technical issue affecting the French nuclear fleet adds to a series of excessive outages for maintenance, repair, and backfitting cumulating in half or more of the reactors being down most of the time in the first half of the year. In May and June 2022, availability never exceeded half of the installed nuclear capacity and dropped as low as one third. The worst is yet to come when electric space heating pushes up consumption in winter. "The current low production of the French nuclear fleet could prove to be a disaster for France", a commentator wrote in the economic daily *Les Echos* under the headline "Power Cuts: Inform the French!"[127]

All of these new problems for an already strained industry did not prevent the French President making a landmark speech on 10 February 2022 hailing a "French nuclear renaissance". While current legislation stipulates the closure of a dozen reactors until 2035 and the reduction of the nuclear share in the power mix to 50 percent, the President wishes that "six EPR2 be built and that we launch the studies for the construction of eight additional EPR2".[128] For now, the EPR2 does not even exist on the drawing board, no detailed design is available yet. The government administration estimated in October 2021 in an 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 have in the past and do currently—it could take until 2043 to commission the first EPR2, the project review states.[129]

The government had asked EDF to "prepare a comprehensive file with the nuclear industry by mid-2021 relating to a programme of renewal of nuclear facilities in France". EDF has "started to prepare economic and industrial proposals based on the EPR2 technology".[130] However, EDF clearly stated in its annual report 2021 that "No investment decision has yet been taken, and the programme will require appropriate regulation and funding arrangements."[131]

Meanwhile, some estimates put EDF's expected net debt as high as €65 billion (US$67.9 billion) at the end of 2022.[132] Trade union officials let it be known that the company "might not make it through the year".[133] In early July 2022, the government announced it would fully re-nationalize EDF (it currently holds 84 percent). Following the avalanche of disastrous news over the past few years, EDF's shares had plunged below €8 (US$8), less than one tenth of the peak in 2007, picked up a bit due to the nationalization announcement and remained just below the advertised takeover offer of €12 (US$12) per share. However, analysts and commentators were

127 - Agnès Verdier-Molinié, "Coupures de courant : informez les Français!" ["Power cuts: inform the French!"], *Les Echos*, Updated 1 August 2022, see https://www.lesechos.fr/idees-debats/cercle/opinion-coupures-de-courant-informez-les-francais-1779786, accessed 30 August 2022.

128 - Presidency of the French Republic, "Reprendre en main notre destin énergétique !" ["Reclaiming our energy destiny!"], Speech by President Emmanuel Macron, 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.

129 - French Government, "Travaux relatifs au nouveau nucléaire—PPE 2019-2028", as published by *Contexte*, 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.

130 - EDF, "Annual Financial Report 2019—Universal Registration Document", March 2020.

131 - EDF, "Consolidated Financial Statements at 31 December 2021", February 2022.

132 - Christine Kerdellant, "Nationaliser EDF : pour quoi faire ?" ["Nationalise EDF: what for?"], *Les Echos*, 8 July 2022, see https://www.lesechos.fr/idees-debats/editos-analyses/nationaliser-edf-pour-quoi-faire-1775293, accessed 30 August 2022.

133 - Florian Maussion, "EDF : quatre questions sur une nationalisation très politique" ["EDF: four questions on a very political nationalisation"], *Les Echos*, 8 July 2022, see https://www.lesechos.fr/industrie-services/energie-environnement/edf-quatre-questions-sur-une-nationalisation-tres-politique-1775426, accessed 30 August 2022.

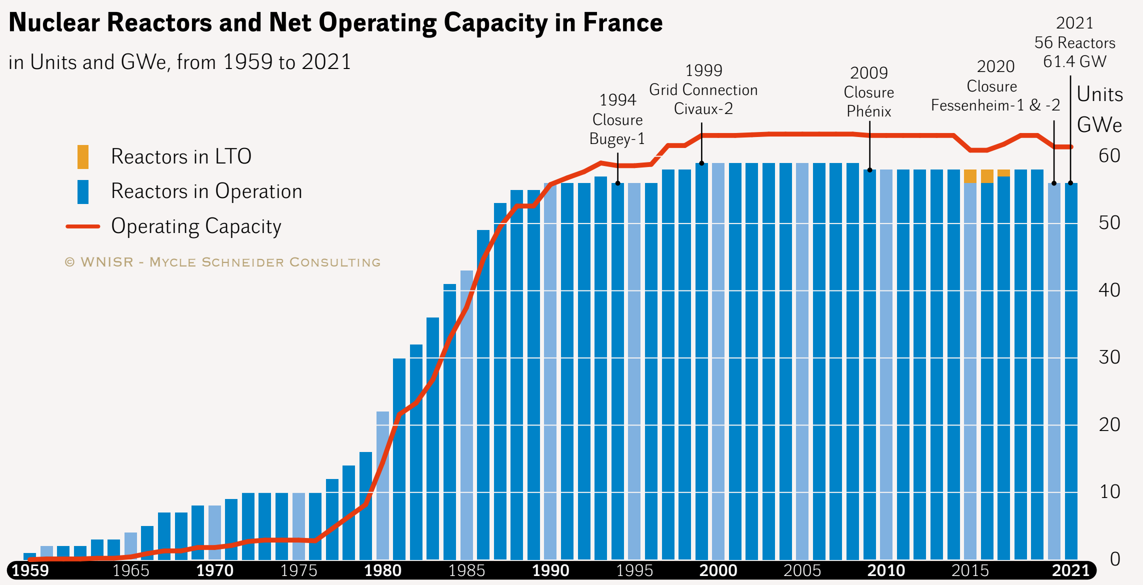
quick in arguing that the nationalization would not solve EDF's problems. As the economic daily *Les Echos* put it:

> What it takes to save EDF is a transformation from top to bottom to increase flexibility and efficiency. However, for the past forty years, the State shareholder never demonstrated it was able to transform mammoths into gazelles.[134]

After Worst Performance in Decades, Worse is Yet to Come

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 and for two units in LTO within the period 2015–2017 (see Figure 23).

Figure 23 · Operating Fleet and Capacity in France



Sources: WNISR with IAEA-PRIS, 2022

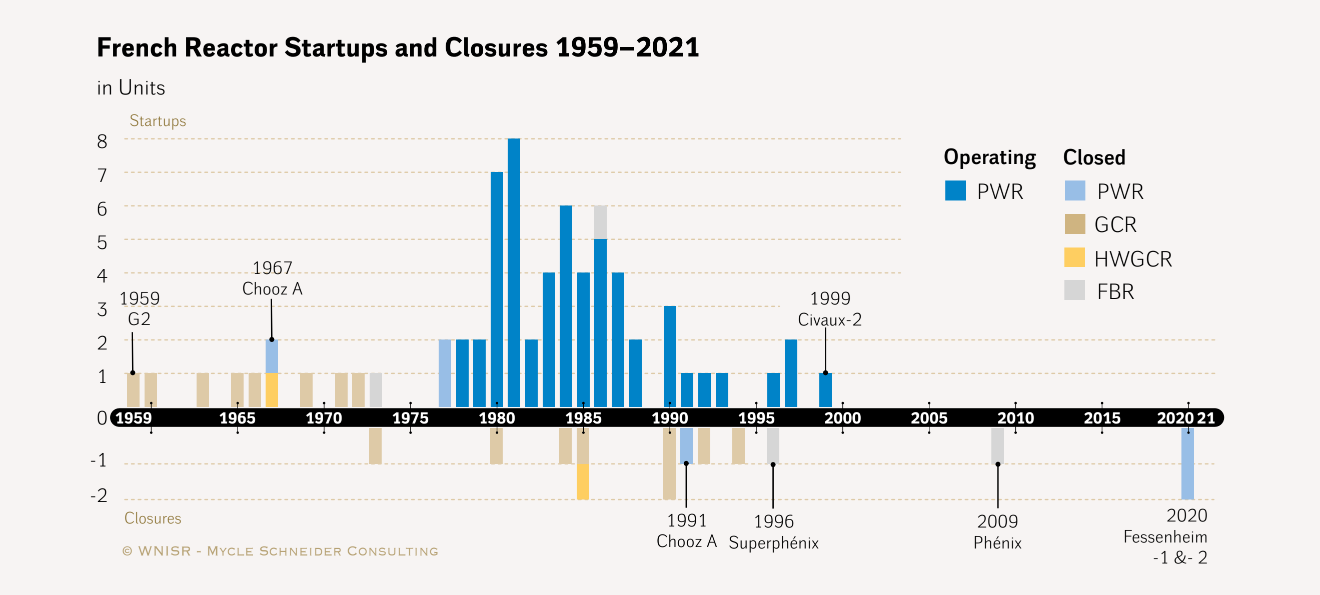
No new reactor has started up since Civaux-2 was connected to the French grid in 1999. The first and only PWR closed prior to Fessenheim was the 300 MW Chooz-A reactor, which was retired in 1991. The other closures were eight first generation natural-uranium gas-graphite reactors, two fast breeder reactors and a small prototype heavy water reactor (see Figure 24).

In 2021, the 56 operating reactors[135] produced 360.7 TWh, a 7.5 percent increase over the previous year, but still below the level of 2019 and the sixth year in a row that generation remained below 400 TWh. 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 25).

134 - *Les Echos*, "Nationaliser EDF : pour quoi faire ?", 8 July 2022, op. cit.

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

Figure 24 · Startups and Closures in France

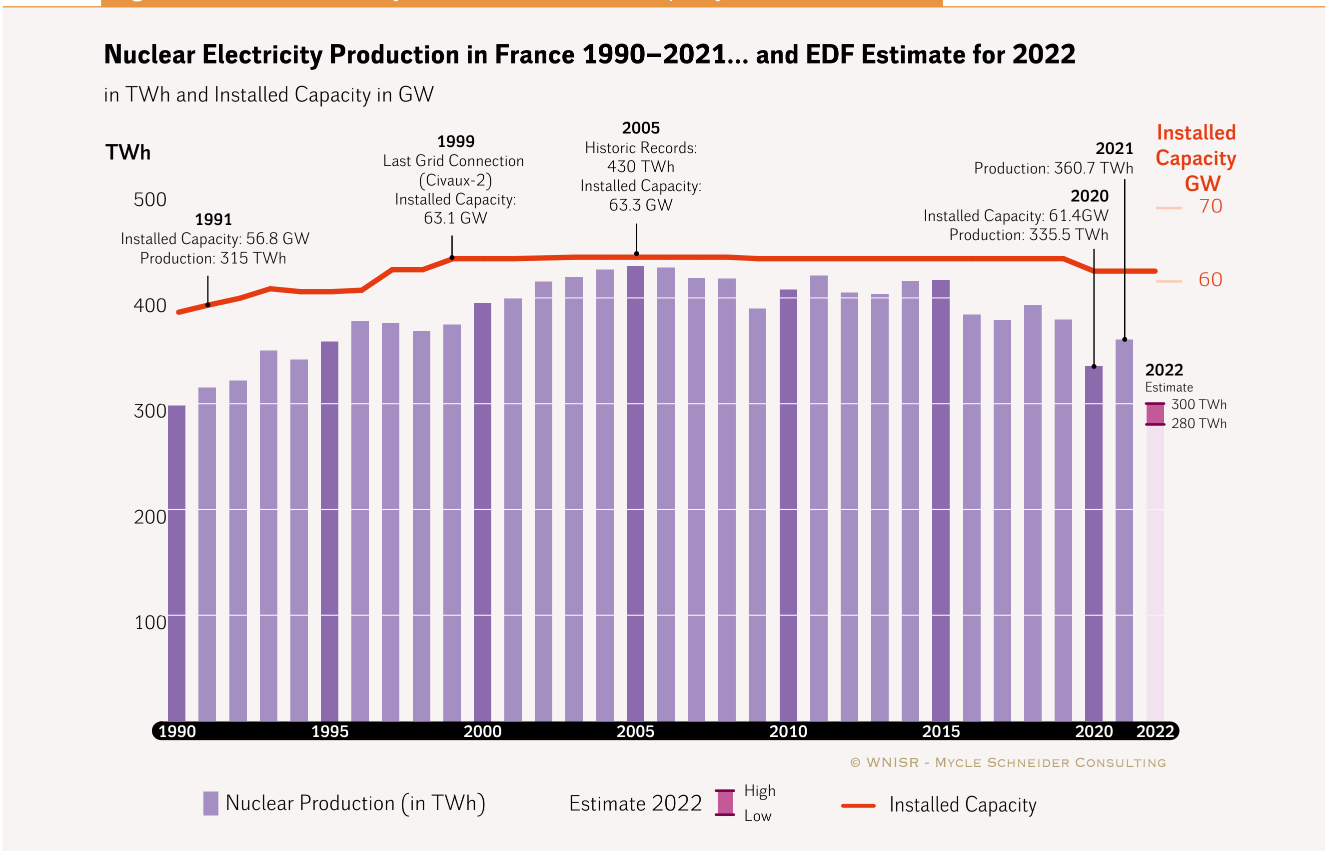


Sources: WNISR, with IAEA-PRIS, 2022

Notes:

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

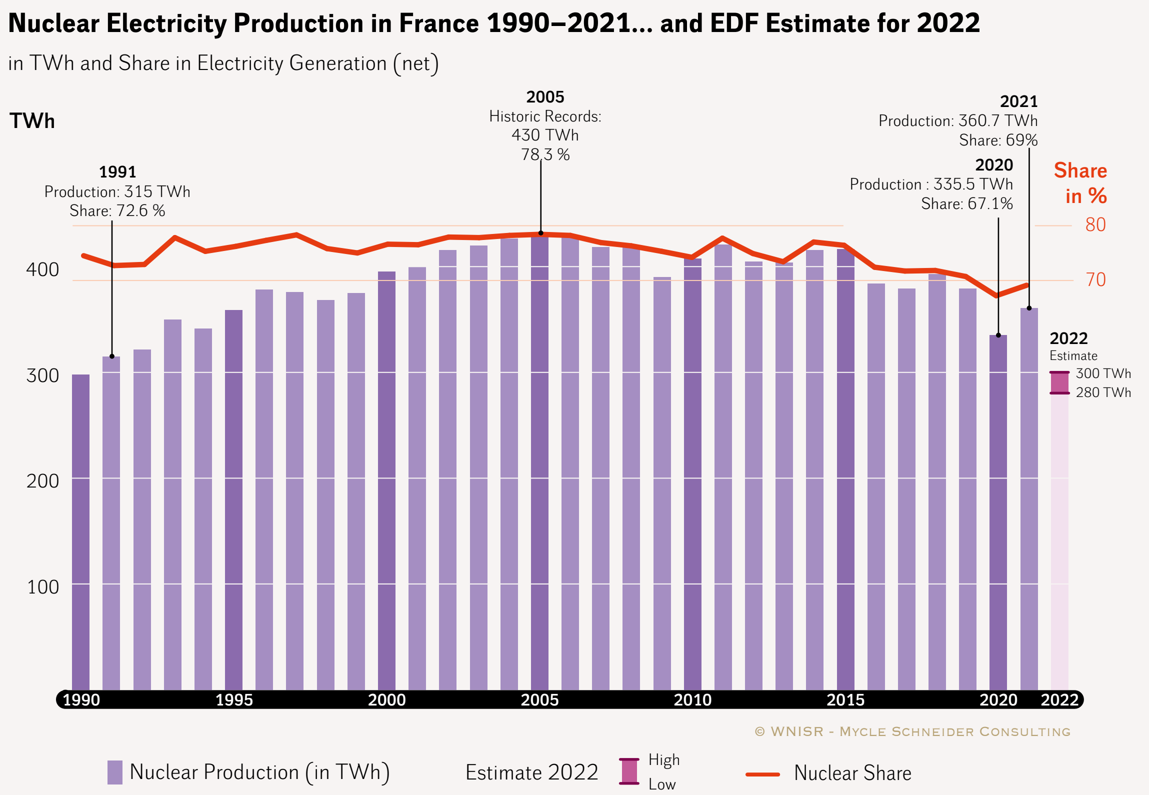
Figure 25 · Nuclear Electricity Production vs. Installed Capacity in France 1990–2022



Sources: RTE, 2000–2022, EDF 2022

In 2021, nuclear plants provided 69 percent (+1.9 percentage points) of the country's electricity following the exceptional plunge in 2020, however remaining below the 2019 level. According to RTE, the nuclear share peaked in 2005 at 78.3 percent. The outlook for 2022 is grim. After several downward revisions, as of mid-2022, EDF estimates of the annual production range at 280–300 TWh, a figure not seen since 1990 (see Figure 25 and Figure 26.)

Figure 26 · Nuclear Electricity Production vs. Nuclear Share in France 1990–2022



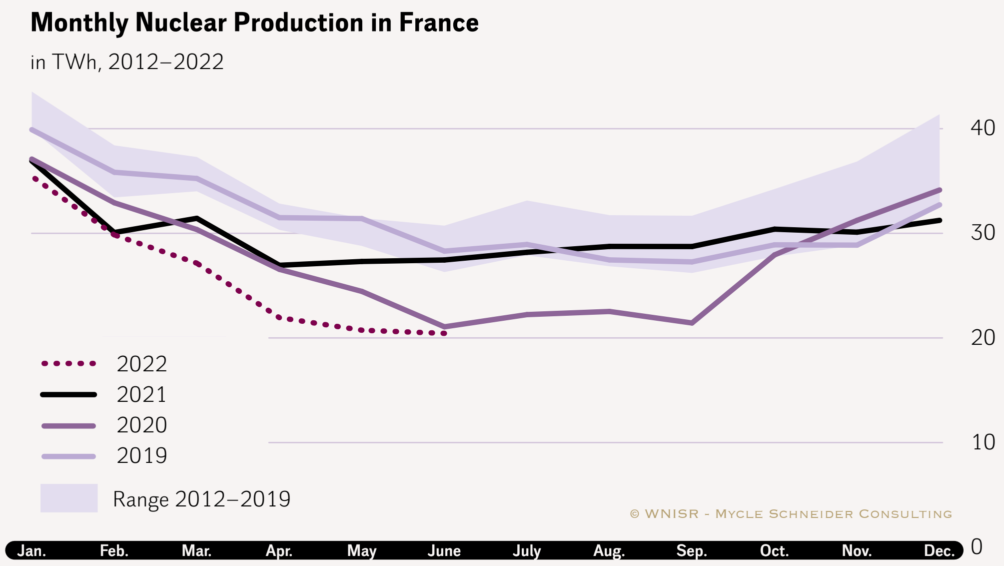
Sources: RTE, 2000–2022, EDF 2022

Monthly production has continued to deteriorate in 2022 with a lower output in every single month of the first half of the year than in any year over the past decade (see Figure 27).

Electricity represented 24.5 percent of final energy in France in 2021. As nuclear plants provided 69 percent of electricity, as in 2020, according to provisional numbers, nuclear plants covered 17 percent of final energy in France in 2021. The largest share being covered by fossil fuels with oil at 42 percent and natural gas at 20 percent, while renewables contributed only 11 percent.[136]

136 - Ministry of Ecological Transition, "Bilan énergétique de la France en 2021 – Données provisoires" ["Energy Balance of France in 2021—Provisional Data"], April 2022.

Figure 27 · Monthly Nuclear Electricity Generation 2012–mid-2022



Source: RTE, "Données Mensuelles" and EDF "Nuclear Generation", 2021–2022

Nuclear Unavailability Review 2021

In 2021, there were 5,810 reactor-days, (down 655 days or 10 percent from the 6,465 reactor-days in 2020), an average of 104 days per reactor, when reactors in France were not producing any power, not including load following or other operational situations with reduced capacity but above-zero. The number is still almost 8 percent higher than the average 96 days per reactor compared to the pre-COVID situation of 2019. All 56 reactors were subject to outages ranging 9–272 days (Figure 29 and see Figure 30).

Table 4 – Total Unavailability at French Nuclear Reactors 2019–2021 (in reactor-days)

	Declared Type of Unavailability			
	"Planned"	Forced	Total	Average per Reactor
2019	5272.9	315.5	5588.3	96.3
2020	6179.1	286.2	6465.3	115.4
2021	5638.6	172.1	5810.8	103.75

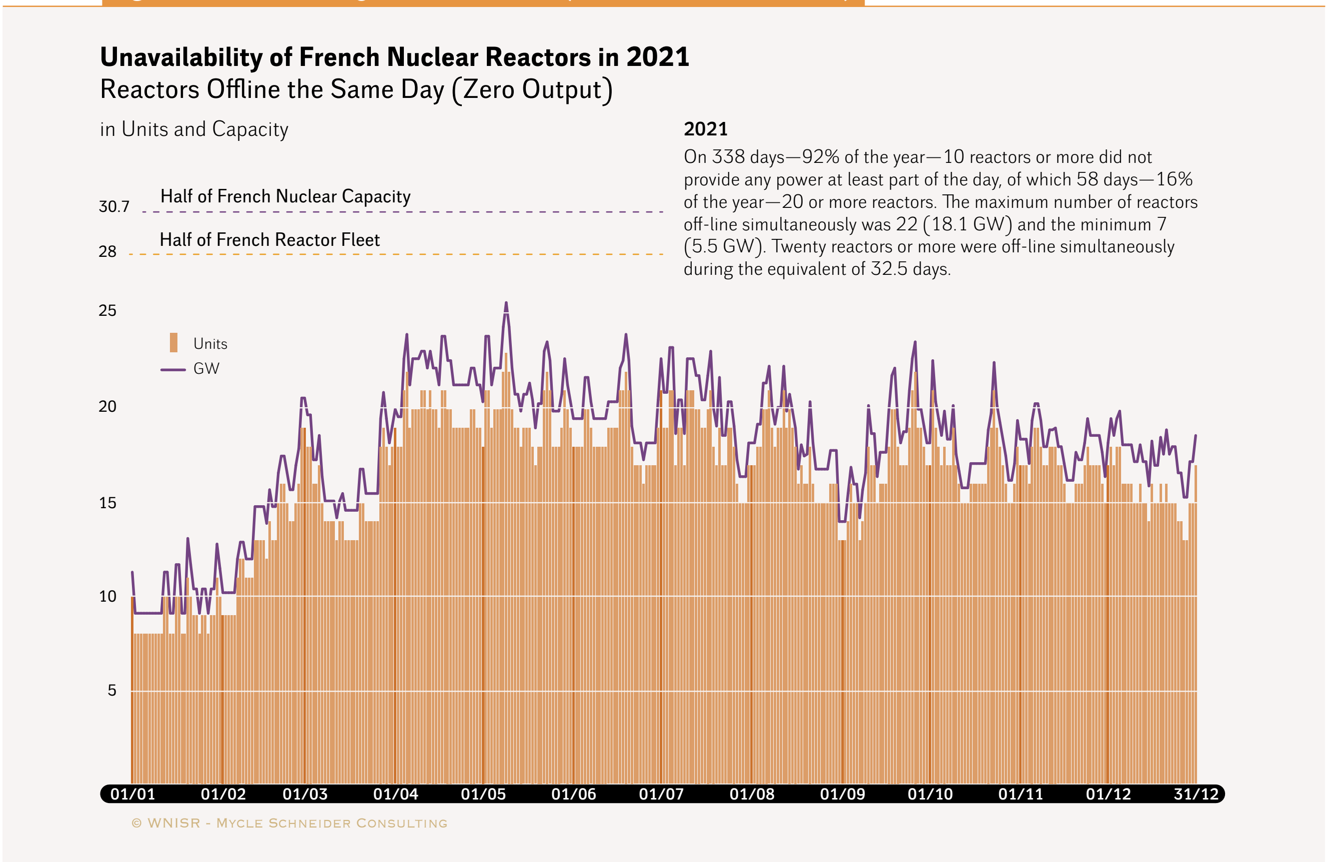
Sources: RTE and EDF REMIT Data, 2019–2022

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".

The unavailability analysis for the year 2021 on Figure 28 further shows:

- On 338 days (92 percent of the year), at least 10 units and up to 23 were down during the same day.
- On 109 days (30 percent of the year), 19 or more units were shut down for at least part of the day.
- At least seven reactors were down (zero capacity) simultaneously at any day of the year.
- At least 20 reactors were offline simultaneously during the equivalent of 32.5 days.

Figure 28 · Reactor Outages in France in 2021 (in number of units and GWe)



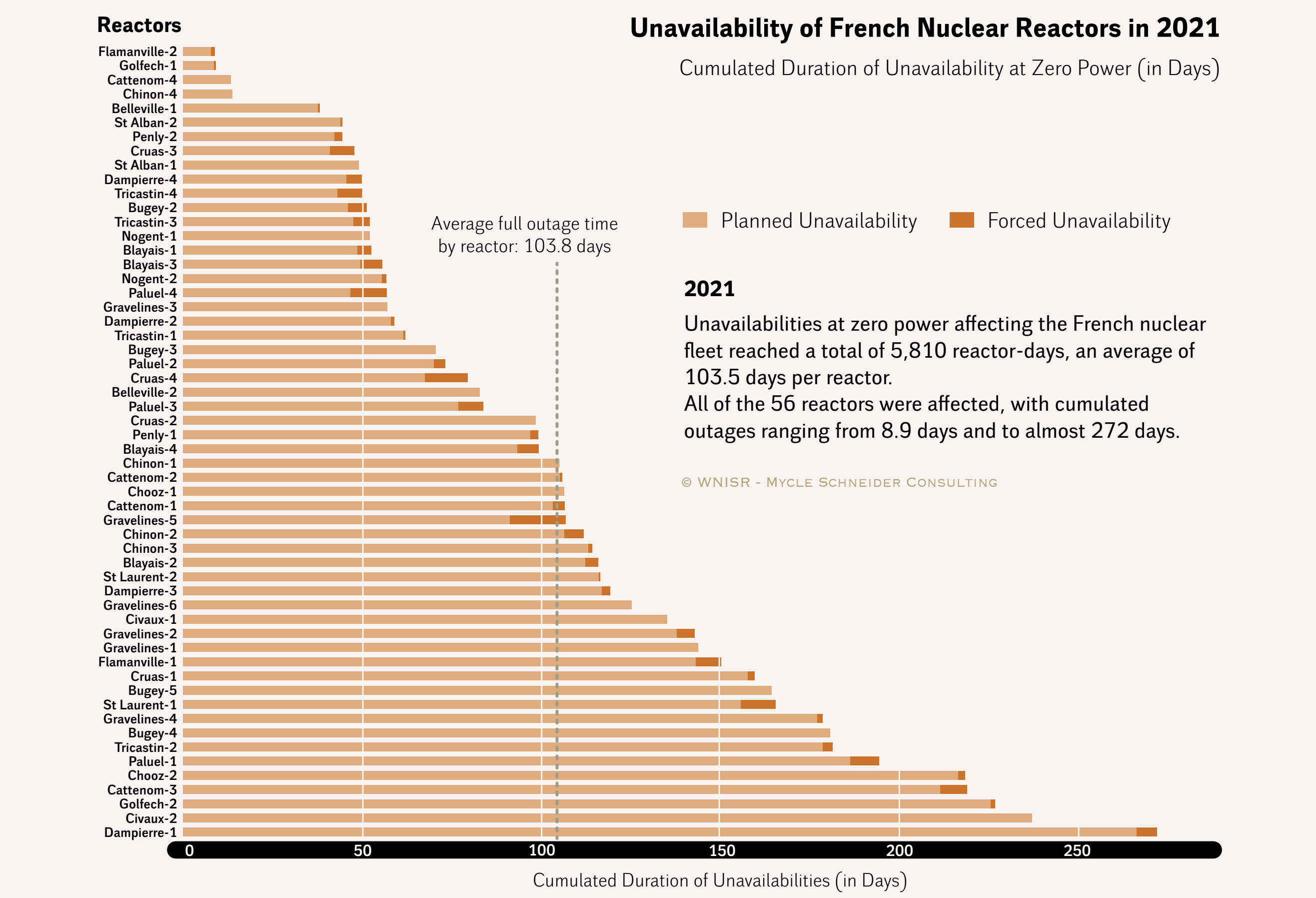
Sources: compiled by WNISR, with RTE and EDF REMIT Data, 2021–2022

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.

According to EDF's classification of "planned" and "forced" unavailabilities, in 2021,

- 16 reactors did not experience any "forced" outage,
- at seven units "forced" outages lasted less than one day,
- at 30 their cumulated duration represented between one and ten days,
- and only three reactors did fall in the range between 11 and 15.5 days of "forced" outage over the year (see Figure 29).

Figure 29 · Forced and "Planned" Unavailability of Nuclear Reactors in France in 2021



Sources: compiled by WNISR, with RTE and EDF REMIT Data, 2021–2022

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.

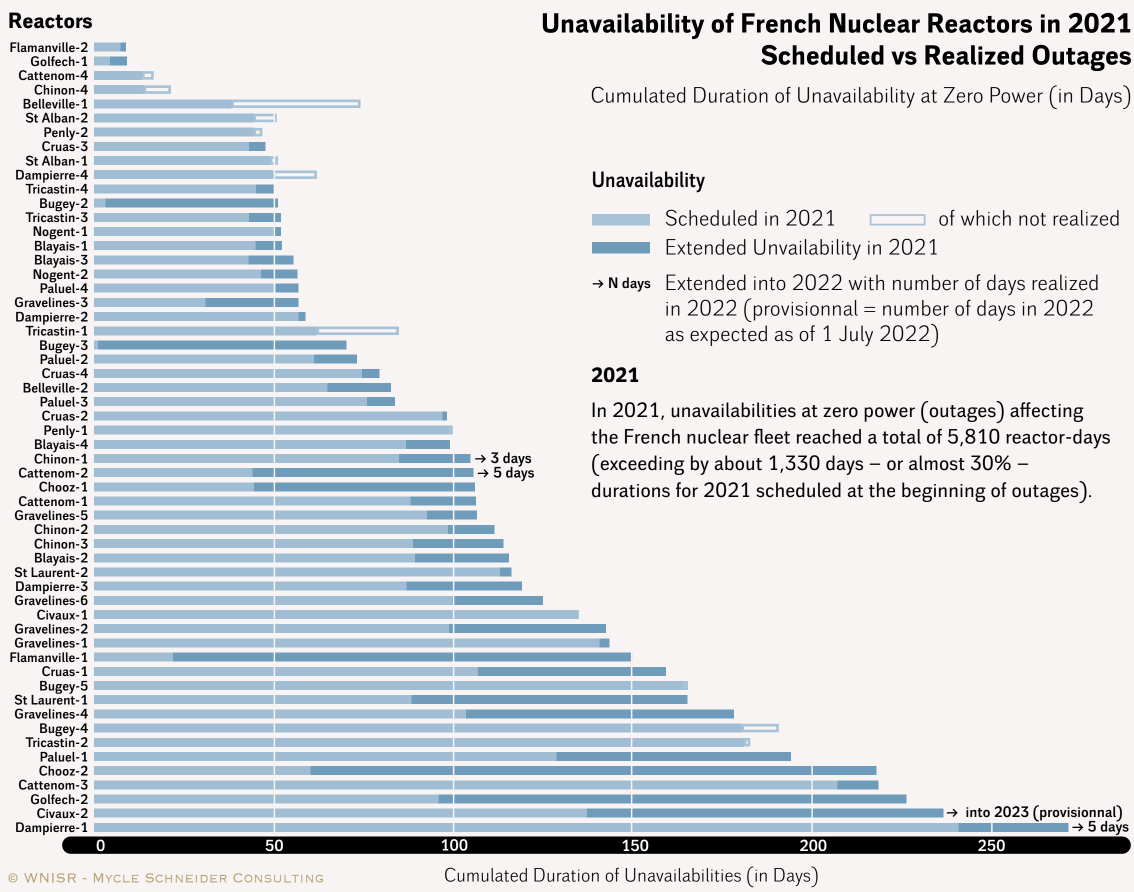
"Planned" and "Forced" unavailabilities as declared by EDF.

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".

WNISR analysis shows a different picture. Of 240 full outages in 2021, 161 were declared "planned" and 79 "forced". In the case of "forced" outages, a generic duration of one day is 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 240 full outages, 86 experienced a prolongation exceeding 1 day and up to 156 days (Chooz-2) in 2021[137]; 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 (see Figure 30).

Figure 30 · Scheduled vs. Realized Unavailability by Nuclear Reactor in France in 2021



Sources: compiled by WNISR, with RTE and EDF REMIT Data, 2021–2022.

Note: This figure represents the cumulated outage duration per reactor as planned at the beginning of the outages and the real durations during the same year (cumulation of planned and forced unavailabilities). In the case of reactors that were shut down in 2020 and planned to restart before 1 January 2021, the entire outage duration in year 2021 is considered outage extension. Extensions into 2022 are not considered.

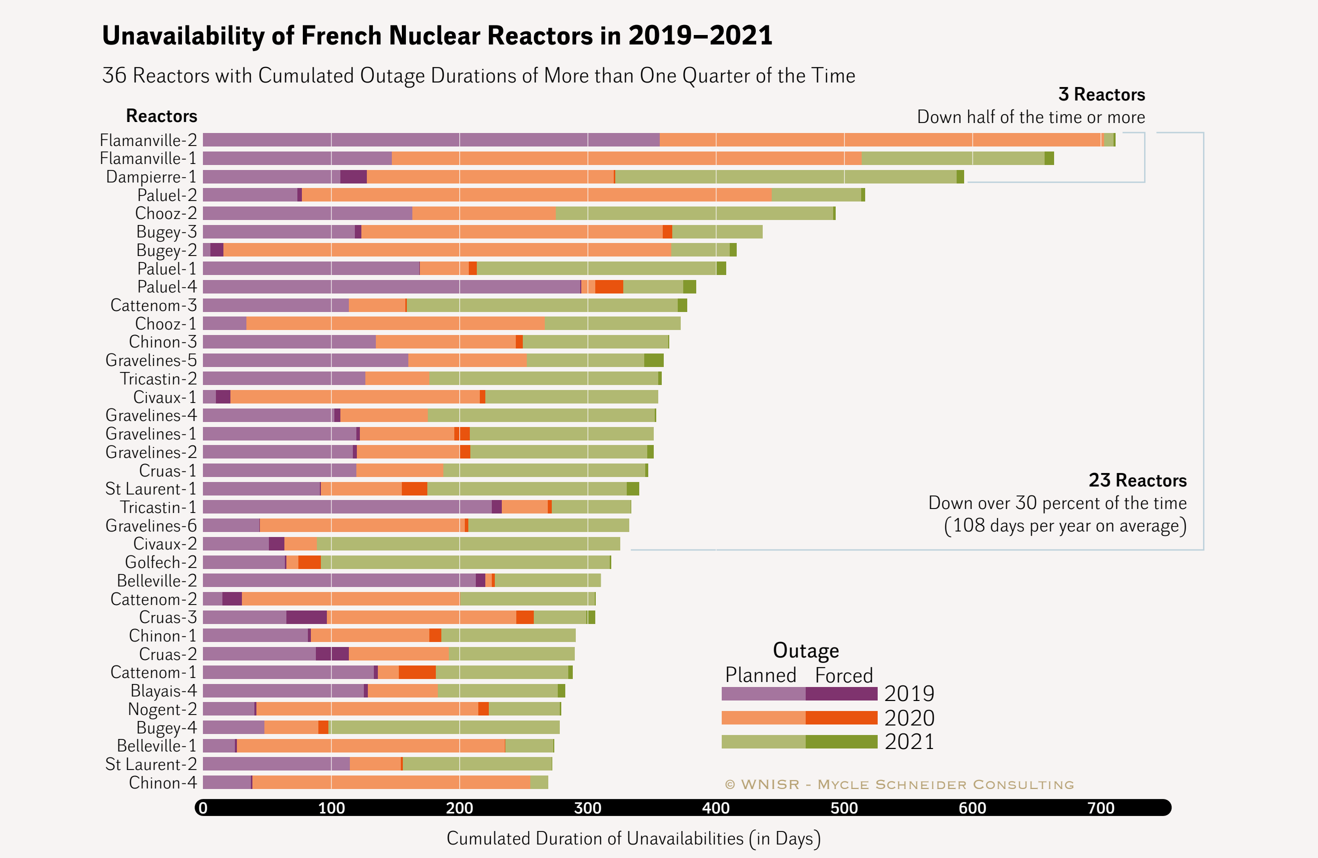
The categories "Extension" and "Not implemented" represent the cumulation of balances between all planned and real outage durations per reactor. These numbers do not consider cancelled or rescheduled outages that were moved into 2022.

137 - 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.

The cumulated outage analysis over the three years 2019–2021 reveals the following (see Figure 31):

- Three reactors were down half of the time or more (Flamanville-1 and -2, Dampierre-1);
- 23 reactors were generating zero power over 30 percent of the time, that is 108 days and more per year on average.

Figure 31 · Unavailability of French Nuclear Reactors 2019–2021



Sources: compiled by WNISR, with RTE and EDF REMIT Data, 2019–2022

Lifetime Extensions – Fact Before License

By mid-2022, the average age of the 56 nuclear power reactors exceeds 37 years (see Figure 32). Lifetime extension beyond 40 years—50 operating units are now over 31 years old of which 18 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. This is (yet) in line with the Government's pluriannual energy plan, which does not envisage any further reactor closures until 2023 and only a limited number in the following years. But President Macron in his February 2022 programmatic speech made it clear that the government has no intention anymore of closing reactors and 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".[138]

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 in 2021… until the COVID-19 pandemic further disrupted the safety review schedule.

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.[139] 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 extended by 25 days. Including further, unrelated unavailabilities, the reactor was in full outage during two thirds of that year (232 days).

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. However, as illustrated, many factors could lead to significantly longer outages. EDF, in fact, 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.[140]

On 23 February 2021, the ASN issued detailed generic requirements for plant life extension.[141] 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.[142]

138 - French Presidency, "Reprendre en main notre destin énergétique !", 10 February 2022, op. cit.

139 - 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" ["Presentation of the 2019 Annual Report of the French Nuclear Safety Authority (ASN) on the Status of Nuclear Safety and Security in France"], ASN, French Nuclear Safety Authority, Hearing before The Parliamentary Office for Scientific and Technological Assessment, French National Assembly, 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.

140 - ASN, "Réexamen périodique associé aux quatrièmes visites décennales des réacteurs du palier 900 MWe", Presentation at a meeting of the local information committee on the major energy facilities at Tricastin, Commission locale d'information des grands équipements énergétiques du Tricastin (CLIGEET), 4 July 2018 (in French), see https://www.ladrome.fr/sites/default/files/5.2_presentation_asn_vd4.pdf, accessed 23 March 2019.

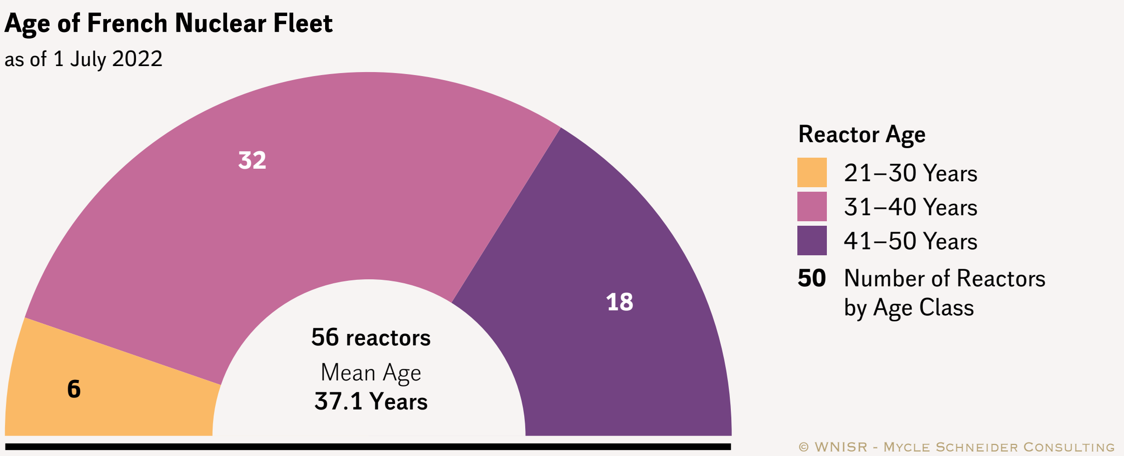
141 - ASN, "L'ASN prend position sur les conditions de la poursuite de fonctionnement des réacteurs de 900 MWe au-delà de 40 ans" ["ASN takes position on the conditions for continued operation of 900 MW-reactors beyond 40 years"], 25 February 2021 (in French), see https://www.asn.fr/Informer/Actualites/La-poursuite-de-fonctionnement-des-reacteurs-de-900-MWe-au-dela-de-40-ans, accessed 25 February 2021.

142 - 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, May 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.

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, e.g. many of the post-Fukushima measures have not yet been implemented eleven years after the events. 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.[143]

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 an example, and it is the most recent 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 32 · Age Distribution of French Nuclear Fleet (by Decade)



Sources: WNISR, with IAEA-PRIS, 2022

The public inquiry for the first unit to undergo relicensing, Tricastin-1—first connected to the grid on 31 May 1980—took place in early 2022. Over 1,800 citizens submitted comments. The Inquiry Committee highlighted in its conclusions formulated numerous complaints the lack or inadequacy of documentation, the absence of a planning overview for the backfitting work to be carried out and the limitation of the invitation to participate to the seven municipalities within a 5-km radius from the plant, rather than the 76 towns within the 20 km radius that is the basis for emergency planning. The Committee report also criticizes that while the public understood the inquiry to be about the decision to extend the lifetime of the reactor, the subject of inquiry is a catalogue of technical modifications proposed by EDF as a result of ASN's

143 - Manon Besnard and Yves Marignac, "Les mesures de renforcement du parc nucléaire français, dix ans après Fukushima" ["Reinforcement measures of the French nuclear fleet, ten years after Fukushima"], Institut négaWatt, 5 March 2021, 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.

requests. None of the Committee members were technically qualified to understand and judge the technicalities involved. The report adds: "Since ASN itself has decided on the provisions even before the public inquiry, the Inquiry Committee wonders how the public's contribution, the conclusions of the Inquiry Committee and the opinion of the communities concerned will be taken into account..."[144] Remarkably, a majority of the members voted nevertheless in favor of the modifications proposed by EDF.

Embattled Clientele, Financial Trouble, Volatile Market

Operating costs have increased substantially over the past few years (see also previous WNISR editions). The Court of Accounts has calculated the operating costs for the year 2019 at €43.8/MWh ($\text{US\$}_{2019}$49/MWh) when using an "accounting" methodology and €64.8/MWh ($\text{US\$}_{2019}$72.6/MWh) when applying an "economic" approach (taking into account past investments) as chosen by the Court. Lifetime extension would cost "at least $€_{2015}$35 /MWh [$€_{2022}$39/MWh or $\text{US\$}_{2022}$40/MWh] based on EDF figures".[145]

Outages that systematically exceed planned timeframes are particularly costly. EDF's net financial debt increased by €8 billion ($\text{US\$}_{2019}$9 billion) in 2019, grew by another €1.2 billion ($\text{US\$}_{2020}$1.5 billion) in 2020, and a further €0.7 billion ($\text{US\$}_{2021}$0.8 billion)—to a total of €43 billion ($\text{US\$}_{2021}$48.7 billion)—as of the end of 2021.[146]

EDF has been losing 100,000–200,000 clients *per month* for several years. As of the end of 2021, EDF's 51 national competitors—in addition, there are over 100 public local utilities—had captured 36 percent of non-residential customers and 31 percent of the residential clients, representing 44 percent of the national demand. In spite of the huge market price increases, EDF lost an additional 100,000 residential clients and 18,000 non-residential customers in the fourth Quarter 2021.[147] On 1 January 2021, EDF lost 300,000 non-residential customers in one go when the regulated tariffs for small commercial users were abolished.[148]

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.[149] The drawback is that during low nuclear production and excessively high prices on the market,

144 - Prefect of Drôme, "EDF, Réacteur Tricastin-1, Espace Procédure", Préfet de la Drome, French Government, 16 December 2021 (in French), see http://www.drome.gouv.fr/st-paul-3-chateaux-edf-reacteur-tricastin-1-a8154.html, accessed 28 June 2022.

145 - French Court of Accounts, "L'analyse des coûts du système de production électrique en France", S2021-2052, 15 September 2021.

146 - 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.

147 - French Energy Regulatory Commission, "La CRE publie son observatoire des marchés de détail de l'électricité et du gaz naturel pour le 4ème trimestre de l'année 2021.", Commission de Régulation de l'Énergie, 25 March 2022, see https://www.cre.fr/Actualites/la-cre-publie-son-observatoire-des-marches-de-detail-de-l-electricite-et-du-gaz-naturel-pour-le-4eme-trimestre-de-l-annee-2021, accessed 29 March 2022.

148 - French Energy Regulatory Commission, "Délibération de la Commission de régulation de l'énergie du 18 mars 2021 portant communication sur le déroulé des échéances relatives à la fin partielle des tarifs réglementés de vente d'électricité et à la suppression des tarifs réglementés de vente de gaz naturel", Deliberation 2021-84, Commission de Régulation de l'Énergie, 18 March 2021.

149 - 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.

this forces 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.[150]

The Flamanville-3 EPR Saga Continued

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, ASN still drew attention to the "need to reinforce skills, professional rigorousness and quality within the nuclear sector".[151]

In December 2007, 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. These problems never stopped. In April 2018, it was discovered that the main welds in the secondary steam system did not conform with the technical specifications; so by the end of May 2018 EDF stated that repair work might again cause "a delay of several months to the start-up of the Flamanville 3 European Pressurized Water Reactor (EPR) reactor."[152]

In October 2019, EDF had stated that fuel loading would be delayed to "late 2022" and construction costs had been re-evaluated at €12.4$_{2015}$ billion (US\$$_{2015}$13.9 billion), an increase of €1.5$_{2015}$ billion (US\$$_{2015}$1.7 billion) over the previous estimate.[153]

In July 2020, the French Court of Accounts estimated that additional costs arising until startup of the unit—then expected to occur by mid-2023—could reach €$_{2015}$6.7 billion (US\$$_{2015}$7.4 billion), including €4.2 billion in financial costs, thus reaching a total of €$_{2015}$19.1 billion (US\$$_{2022}$19 billion). Deploring the absence of projected profitability calculations, the Court stated that FL-3 electricity could possibly be generated at €$_{2015}$110–120/MWh (US\$$_{2015}$123–134/MWh).[154]

None of these numbers take into account the COVID-19 effect, and already in July 2020, EDF warned that the several weeks long construction interruption at the Flamanville EPR "could result in further delays and additional costs".[155]

In January 2022, EDF released an "adjusted timetable" and a new estimate of the overnight costs at €$_{2015}$12.7 billion (US\$$_{2015}$14.2 billion), without interim interests.[156]

150 - Ibidem.

151 - 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.

152 - EDF, "Quality deviations on certain welds of the secondary circuit at the Flamanville EPR: the investigation continues", Press Release, 31 May 2018, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/quality-deviations-on-certain-welds-of-the-secondary-circuit-at-the-flamanville-epr-the-investigation-continues, accessed 7 June 2018.

153 - EDF, "Annual Financial Report 2019 – Universal Registration Document", March 2020.

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

155 - EDF, "2020 Half-Year Results", Press Release, 30 July 2020, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/publications/financial-results/h1-2020/20200730-h1-2020-cp-en.pdf, accessed 30 August 2022.

156 - EDF, "Update on the Flamanville EPR", 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.

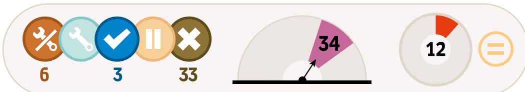
Known technical issues cumulate with new ones. ASN notes in its 2021 Review:

> Considerable works and examinations still remain before commissioning of the reactor. This in particular concerns the design and reliability of the primary system valves, repairs to the main secondary system welds, with anomalies on three nozzles of the main primary system and post-weld heat treatment of the nuclear pressure equipment, the performance of the filtration system on a containment internal water tank, and the various anomalies detected on the cores of the Taishan EPR reactors, including the fuel clad ruptures observed in 2021.[157]

Especially the issue that struck the Taishan EPRs and kept Unit 1 off the grid for over one year—it was eventually restarted in mid-August 2022—has consequences on FL3. EDF has proposed to refabricate 64 of the 241 fuel assemblies that have already been produced for FL3. According to EDF's plan, certain assembly components would undergo thermal treatment prior to use, others would be replaced by and by on all fuel assemblies. The plan has yet to be assessed by the Institute for Radiation Protection and Nuclear Safety (IRSN) and to be approved by ASN.[158]

EDF assures that the issue "does not question the design of the EPR".[159]

GERMANY FOCUS



Introduction

Germany decided immediately after 3/11 to close eight of the oldest[160] of its then 17 operating reactors and to progressively phase out the remaining nine by the end of 2022, effectively reactivating a "consensus agreement" negotiated a decade earlier (see Table 5 for the phaseout schedule). This choice was implemented by a conservative, pro-business, and, until the Fukushima disaster, very pro-nuclear Government, led by physicist Chancellor Angela Merkel. With no political party dissenting, it looked like virtually irreversible under any political constellation. On 6 June 2011, the German Bundestag passed a seven-part energy transition legislation almost by consensus and it came into force on 6 August 2011 (see earlier WNISR editions for details).

A decade later, in September 2021, legislative elections saw the Social Democrats (SPD) become the strongest 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" coalition-government was formed by adding the Liberal Democratic Party FDP (yellow) to the SPD (red) and Greens.

157 - ASN, "ASN Report on the state of nuclear safety and radiation protection in France in 2021—Abstracts", May 2022, op. cit.

158 - Sfen, "L'EPR Taishan 1 Redémarre" ["Taishan-1 EPR Restarts"], Société française d'énergie nucléaire/French Nuclear Energy Society, *Revue Générale Nucléaire*, Updated 25 August 2022, see https://www.sfen.org/rgn/lepr-taishan-1-redemarre/, accessed 31 August 2022.

159 - EDF, "Update on the Flamanville EPR", 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.

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

One year into the legislative period, on 5 September 2022, Robert Habeck, Minister for 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, he will recommend to the government to transfer two of the three remaining operating nuclear reactors into "reserve status" as of the end of 2022. He made it very clear what it means:

> This also means that all three of the nuclear power plants currently still on the grid in Germany will be taken off the grid as planned at the end of 2022. We are sticking to the nuclear phase-out stipulated in the Atomic Energy Act. New fuel elements will not be used, and the deployment reserve will be terminated in mid-April 2023. Nuclear power is and continues to be a high-risk technology, and the highly radioactive waste will be a problem for many future generations. You can't play around with nuclear power. [161]

What happened? Why would the consensus-driven nuclear-phaseout decision even be questioned? 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 an unexpected opportunity for a few remaining 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—the same handful of individuals could publish their pro-nuclear lobbying pieces in top German media like *Der Spiegel*, *Die Zeit*, *Focus*, and the likes—some prominent journalists took it on, and a few conservative politicians started questioning the phaseout legislation.

The war in Ukraine triggered an astounding 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 have shown 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 with the hope for more independence from Russian gas.[162] A mirage, as the latest stress test illustrated, since less than 1 percent of gas burnt for power could potentially be saved.

An Unexpected Debate Over Potential Lifetime Extensions

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

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

162 - 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" ["Majority in favor of longer NPP lifetimes"], 24 June 2022, see https://www.tagesschau.de/inland/deutschlandtrend/deutschlandtrend-3051.html, accessed 10 September 2022.

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:[163]

- 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.[164]
- 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 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."[165] The proposal was rejected by all of the parliamentary committees and, on 7 July 2022, received a unanimous rejection by

163 - BMWK and BMUV, "Prüfung des Weiterbetriebs von Atomkraftwerken aufgrund des Ukraine-Kriegs" ["Examination of Continued Operation of Nuclear Power Plants Due to the Ukraine War"], Federal Ministry for Economic Affairs and Climate Action, and Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, Federal Government of Germany, 8 March 2022 (in German), see https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Nukleare_Sicherheit/laufzeitverlaengerung_akw_bf.pdf, accessed 13 September 2022.

164 - It has been argued that the reactors could go into "stretch operation" (Streckbetrieb), lowering generation in the summer and save 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.

165 - German Bundestag, "Keine Abschaltung von Kernkraftwerken—Erst recht nicht in einer neuen Realität" ["No Closure of Nuclear Reactors—Especially Not in a New Reality"], Drucksache 20/1021, Motion introduced by Dr. Rainer Kraft, Karsten Hilse et al, and Parliamentary Group AfD, 15 March 2022, see https://dserver.bundestag.de/btd/20/010/2001021.pdf, accessed 13 September 2022.

all parliamentary groups from the far left to the Christian democrats. The vote ended 581 to 67, whereas only AfD members and four independents voted for the proposal.

Since then, some remarkable developments occurred, including 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 EU-Environmental Impact Assessment legislation and ESPOO Convention.[166]
- 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."[167]

"Former Environment Minister, Jürgen Trittin stated: 'If one seriously wanted to change the nuclear law, it will not work without a party congress'"

- 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 are 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.[168]
- On 29 July 2022, Green MP and former Environment Minister, Jürgen Trittin stated: "If one seriously wanted to change the nuclear law, it will not work without a party congress".[169] Early September 2022, a circulating draft motion for the regular Green Party congress scheduled for October 2022 is calling 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."[170]

166 - Ulrich Wollenteit, "Stellungnahme zu der von der TÜV SÜD Industrie Service GmbH erstellten und auf der Seite des Staatsministeriums für Umwelt und Verbraucherschutz des Freistaates Bayern veröffentlichten „Bewertung der konkreten erforderlichen technischen Maßnahmen für einen Weiterbetrieb des KKI 2 bzw. eine Wiederinbetriebnahme des Blocks C des KRB II"" ["Statement on the Report Prepared by TÜV SÜD Industrie Service GmbH and published on the Website of the Bavarian State Ministry for the Environment and Consumer Protection Titled "Assessment of the Concrete Technical Measures Required for the Continued Operation of KKI 2, or Rather the Recommissioning of Unit C of KRB II"], Rechtsanwälte Günther, commissioned by Greenpeace, 22 July 2022 (in German), see https://www.greenpeace.de/publikationen/20220729-greenpeace-stellungnahme-guenther-akw-laufzeitverlaengerung.pdf, accessed 14 September 2022.

167 - *Tagesschau, "Atomkraftwerke sollen bis 2024 laufen"* ["Nuclear Power Plants Must Operate Until 2024"], 26 July 2022, see https://www.tagesschau.de/inland/fpd-atomkraftwerke-laufzeit-energiekrise-gas-ukraine-101.html, accessed 10 September 2022.

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

169 - Felix Hackenbruch and Georg Ismar, "Ampel-Koalition im Krisenmodus: Trittin in Atomfrage für Parteitagsbeschluss der Grünen" ["Traffic-light Coalition in Crisis Mode"], *Der Tagesspiegel Online*, 29 July 2022, see https://www.tagesspiegel.de/politik/trittin-in-atomfrage-fur-parteitagsbeschluss-der-grunen-8542462.html, accessed 10 September 2022.

170 - Markus Decker, "Atomkraft: Grüne Basis will Laufzeitverlängerung stoppen" ["Nuclear Power: Green Base Wants to Stop the Lifetime Extensions"], 1 September 2022, see https://www.rnd.de/politik/atomkraft-gruene-basis-will-laufzeitverlaengerung-stoppen-GSAXELPJ2ZB7LNSWNAUA7JUI2Y.html, accessed 10 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 has 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. Between mid-August and mid-September 2022 (at the time of writing), the available nuclear capacity in France never reached even half of the winter target level and the country continuously depended on power imports, most of it from Germany. Thus, the French assurances seem to be based on highly optimistic assumptions, and the German grid operators have judged it necessary to model scenarios with a French nuclear capacity limited to 45 GW (in Scenario ++) and 40 GW (in Scenario +++) respectively.[171] The most severe scenario combines 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.[172]

The continued generation of the remaining 4 GW of nuclear power would ease capacity constraints and improve grid security to a limited extent. In the median Scenario ++, capacity needs would be narrowly covered but grid security would only lower redispatch needs (power imports) by 0.5 GW, from 5.1 GW to 4.6 GW.

Under the most severe assumptions in Scenario +++, capacity would not be covered for a cumulated 3–12 hours (not continuous) in total over the winter, with 7–8 GW and the supply of 17–53 GWh missing. For Europe—Germany has transmission links to 11 European countries—the extreme case would lead to a shortage in a cumulated 91 hours (3.8 days) with a peak of 18–19 GW and 682 GWh short of demand (Germany included).[173]

According to assumptions under the stress test, the three reactors could generate with their current cores a cumulated total of about 5 TWh beyond year-end, that corresponds to about 52 days if operated at nominal capacity. That appears a lot considering a few hours of load constraints under the most severe assumptions, and not enough to make a major difference over the entire winter. And, of course, considering the legal, technical, safety-related, and political hurdles, there is no guarantee that they would actually generate power.

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 neighbouring countries having enough power stations

171 - 50Hertz, Amprion, Tennet and Transnet, "Sonderanalysen Winter 2022/2023—Ergebnisse & Empfehlungen" ["Special Analysis Winter 2022/2023—Results and Recommendations"], 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 9 September 2022.

172 - Federal Ministry for Economic Affairs and Climate Action, "FAQ Liste Zweiter Stresstest und Maßnahmen zur Sicherung der Stromnetz-Stabilität im Winter 22/23", Federal Government of Germany, 5 September 2022, see https://www.bmwk.de/Redaktion/DE/Downloads/F/faq-zweiter-stresstest-massnahmen-sicherung-stromnetz-stabilitat.pdf?__blob=publicationFile&v=8, accessed 14 September 2022.

173 - 50Hertz, Amprion, Tennet and Transnet, "Sonderanalysen Winter 2022/2023—Ergebnisse & Empfehlungen", September 2022, op. cit.

available to help stabilise our power grid at short notice in the event of grid congestion."[174] 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. The two reactors shall "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."[175] It remains to be seen, how Green Party members will appreciate the proposal, and whether the proposal proves practicable.

Certain other countermeasures recommended by the grid operators are already in preparation, including additional production in biogas plants and the increase of transmission capacity and effectiveness. The ministry clarifies that the two nuclear units shall 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."[176]

The idea is to monitor European capacity availability throughout the winter and, should it appear in November or early December 2022 that a severe shortage could appear in January 2023—e.g. due to lower French nuclear capacity than expected—the two southern reactors would keep operating until their fuel is exhausted. Otherwise, the units would be shut down at year-end as stipulated under the current legislation and restarted only should a crisis situation occur later in the winter. This would not be a stop-and-go kind of operation, but once restarted, the reactors would keep operating until fuel exhaustion. Germany has been a net exporter to France for many years, especially in winter.

Meanwhile, the French government, faced with an unprecedented unavailability level of its own nuclear power fleet (see France Focus), has 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.[177]

The organization of two units as "reserve" power plants will not be easy. There is no precedent, and there is no available protocol as for other reserve power plants. What does it mean for staff availability, for continuous inspection and maintenance, insurances, civil liability, etc.?

Following the publication of the stress test results and the conclusions of the Ministry of Economy and Climate Protection, coalition partner FDP reiterated the call for a lifetime expansion at least until 2024. The party leader of the Christian Democrats, Friedrich Merz, has called the potential closure of the three reactors at year end "completely absurd".[178]

174 - Federal Ministry for Economic Affairs and Climate Action, "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, September 2022, op. cit.

175 - Ibidem.

176 - Ibidem.

177 - *Les Echos*, "Un « deal » franco-allemand et un appel à la sobriété pour éviter la panne de courant" ["A French-German "deal" and a call for sufficiency to avoid blackouts"], 5 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 11 September 2022

178 - *AFP* and *ZDF*, "Kernkraftwerke: FDP und CDU wollen dauerhaften Weiterbetrieb", as published on *ZDF.de*, 6 September 2022 (in German), see https://www.zdf.de/uri/532a315e-d1f6-4c43-8cea-7357c1029527, accessed 11 September 2022.

Nuclear Power vs. Renewables and Fossil Fuels

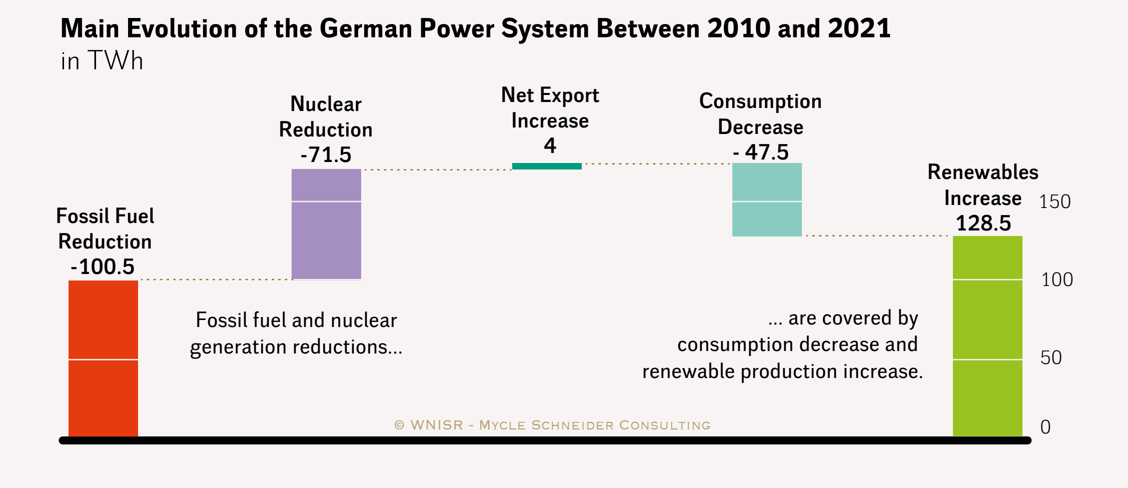
Germany's nuclear fleet generated 65.4 TWh net in 2021, a 7.4 percent increase after a 14 percent decline in 2020, and only a fraction of the peak generation of 162.4 TWh in 2001. Nuclear plants provided 11.9 percent (+0.6 percentage points) of Germany's electricity generation, compared to the historic maximum of 35.6 percent in 1999, according to data from AGEB.[179]

Renewables generated 234 TWh (gross), a significant 7-percent-decline over the previous year, mainly due to a particularly weak wind year with onshore generation dropping by close to 15 percent and offshore wind by almost 11 percent. Consequently, the share of renewables dropped below 40 percent again to 39.7 percent of gross national electricity generation. Nevertheless, wind power remains ahead of nuclear power which it has out generated since 2017.[180]

Figure 33 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 2021.

While the increase in renewables (+128.5 TWh) and the decline in consumption (-47.5 TWh) still overcompensate the decline in fossil fuel (-100.5 TWh) and nuclear generation (-71.5 TWh), all indicators are in retreat compared to 2020.

Figure 33 · Main Developments of the German Power System Between 2010 and 2021



Sources: WNISR based on AG Energiebilanzen (AGEB), 2022

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. However, lignite generation remained below the 2019-level and 25 percent below the 2010 level.

179 - AGEB, "Auswertungstabellen zur Energiebilanz Deutschland – Daten für die Jahre von 1990 bis 2021", September 2022.

180 - AGEB, "Stromerzeugung nach Energieträgern (Strommix) von 1990 bis 2021 (in TWh)—Deutschland insgesamt (Datenstand April 2022)", ["Electricity Generation by Source (Electricity Mix) from 1990 to 2021 (in TWh)—Total Germany (Data as of April 2022)"], Arbeitsgemeinschaft Energiebilanzen/Working Group on Energy Balances, 26 April 2022, see https://ag-energiebilanzen.de/wp-content/uploads/2022/03/STRERZ_2021Feb22_web.pdfhttps://ag-energiebilanzen.de/wp-content/uploads/2022/03/STRERZ_2021Feb22_web.pdf, accessed 11 September 2022.

- Hard coal also peaked in 2013 then dropped to 64 percent below the 2010-level. While it has seen, at 27.7 percent, the strongest increase in 2021 of any power generation technology, it also remains below the 2019 numbers.
- Natural gas fluctuated since 2010 and peaked in 2020 at 2.6 percent above the 2010-level before dropping by 5.3 percent in 2021.

Table 5 – Legal Closure Dates for German Nuclear Reactors 2011–2022

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	31 December 2022

Sources: German Atomic Energy Act/Atomgesetz, 31 July 2011; Atomforum Kernenergie, May 2011; WNISR with IAEA-PRIS, 2022[181]

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%.

The provisional half-year results for 2022 show significant changes in the power generation (gross) compared to the same period in the previous year:[182]

- Nuclear generation dropped (due the closure of three reactors at year-end) by half and represented only 5.6 percent of national production.
- Natural gas-based production declined by a further 11.7 percent and covered 14.6 percent (-2.3 percentage points).

181 - German Bundestag, "Dreizehntes Gesetz zur Änderung des Atomgesetzes", signed into Law on 31 July 2011, *Bundesgesetzblatt*, Nr. 43, 5 August 2011; and "Atomforum Kernenergie", May 2011,

182 - Data mainly from Michael Nickel, "Entwicklungen in der deutschen Stromwirtschaft – 1. Halbjahr 2022" ["Developments in the German Power Industry – First Half-year 2022"], Bundesverband der Energie- und Wasserwirtschaft e.V., Presentation at AGEB Summer Conference, Working Group on Energy Balances, 29 July 2022.

- The share of lignite plants is up by 1.7 percentage points to reach 19.1 percent.
- Hard coal burning represented 10.2 percent of production, up 2 percentage points.
- Renewables generated 14 percent more power and gained 4.6 percentage points to contribute 46.4 percent of electricity generation.

The geopolitical situation provided a strong incentive for the expansion of renewables. But while solar capacity expanded by 3.6 GW in the first half-year 2022—about as much as in the record years 2010–2012—land-based wind energy additions have been modest at 0.9 GW and no offshore capacity was added yet.[183]

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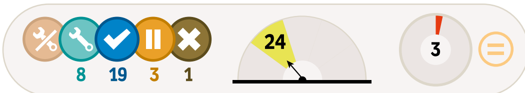


India has 19 operational nuclear power reactors, with a total net generating capacity of 6.3 GW. Even though it is listed as operational by the Nuclear Power Corporation of India (NPCIL) and placed since July 2022 "in LTS" in the International Atomic Energy Agency's (IAEA) Power Reactor Information System (PRIS), the Rajasthan-1 reactor is considered by WNISR to be permanently closed because it has not generated power since 2004.[184] Three units fall under the LTO category: Tarapur-1, Tarapur-2, and Madras-1, as these have not generated any electricity in 2021 and in the first half of 2022.

"The latest reactor to be connected to the grid, Kakrapar-3, has been performing erratically."

Eight more reactors, with a combined capacity of 6.0 GW, are under construction. These include four VVER-1000s at Kudankulam, the last of which had first-pour of structural concrete in December 2021. There are also three Pressurized Heavy Water Reactors (PHWR)—including one at Kakrapar (under construction since November 2010) and two at Rajasthan (since July and September 2011)—and a Prototype Fast Breeder Reactor (PFBR) that has been under construction since October 2004.

According to the IAEA, nuclear power contributed 39.8 TWh net of electricity in 2021, marginally less than 40.4 TWh in 2020. This represents a share of 3.2 percent of total power generation, compared to 3.3 percent in 2020.[185]

The latest reactor to be connected to the grid, Kakrapar-3, has been performing erratically. In November 2021, the NPCIL petitioned the Central Electricity Regulatory Commission to delay the start of commercial operation and requested that the reactor continue to inject "infirm

183 - AGEE, "Schätzung zur Entwicklung der erneuerbaren Energien im 1. Halbjahr 2022", Presentation at AGEB Summer Conference, Working Group on Energy Balances, 29 July 2022.

184 - *Deccan Herald*, "End of the road for RAPS 1", 6 September 2014, see https://www.deccanherald.com/content/429550/end-road-raps-1.html, accessed 16 January 2020.

185 - IAEA, "Nuclear Power Reactors in the World—2022 Edition", Reference Data Series No. 2, June 2022, see http://www-pub.iaea.org/MTCD/Publications/PDF/RDS-2-42_web.pdf, accessed 22 June 2022; and IAEA, "Nuclear Power Reactors in the World—2021 Edition", Reference Data Series No. 2, July 2021, see https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-2-41_web.pdf, accessed 31 August 2022.

power" into the grid until 9 July 2022.[186] As of July 2022, the NPCIL website had not reported any electricity generation from Kakrapar-3. One report suggests that this performance is due to ventilation and cooling problems.[187]

Strong Push for Renewables

BP 2022 statistical review reports 43.9 TWh gross of nuclear electricity in 2021, with a corresponding figure of 171.9 TWh for non-hydro renewables, with wind contributing 68.1 TWh and solar energy contributing 68.3 TWh.[188] The figures for 2020 are 44.6 TWh (nuclear energy), 152.0 TWh (non-hydro renewables), 60.4 TWh (wind energy), and 58.7 TWh (solar energy). Thus, nuclear energy has come down slightly since 2020, whereas both wind and solar have grown and are contributing about 150 percent of nuclear power each. (See Figure 62).

According to the International Renewable Energy Agency (IRENA), installed capacity of all renewable energy sources has gone up from 60.5 GW in 2012 to 147.1 GW in 2021.[189] Of this, wind and solar energy contribute 40 GW and 49.7 GW respectively; the latter maintains the lead it established over wind energy in 2020.

Ongoing Construction Experiencing Delays and Cost Overruns

Of the eight reactor projects under construction, all are delayed or likely to be delayed. 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 "the 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.[190] An official update from July 2022 reports the anticipated date of commissioning for Kudankulam-3 and -4 as November 2023, 36 months after the original date of November 2020.[191] The November 2023 date apparently represents the commissioning of the Kudankulam-4 unit, as according to the NPCIL website, Unit 3 will be commissioned in March 2023.[192] However, already in July 2021,

186 - Central Electricity Regulator Commission, "Petition No. 241/MP/2021", filed by NPCIL Vs. Western Regional Load Dispatch Centre, November 2021, see https://cercind.gov.in/2021/orders/241-MP-2021.pdf, accessed 24 May 2022.

187 - *Spansen*, "At India's Largest Indigenous Nuclear Reactor, Ventilation & Cooling Issues Have Halted Operations", 24 April 2022, see https://www.spansen.com/2022/04/at-indias-largest-indigenous-nuclear.html, accessed 24 May 2022.

188 - BP, "Statistical Review of World Energy 2022", June 2022, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 12 July 2022.

189 - IRENA, "Renewable Capacity Statistics 2022", International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

190 - Rajya Sabha, "Unstarred Question No. 3286: Status of Work at Kudankulam Power Plant", Department of Atomic Energy, Government of India, answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, 31 March 2022, see http://dae.gov.in/writereaddata/rsusq3286.pdf, accessed 7 April 2022.

191 - MoSPI, "440th Flash Report on Central Sector Projects (Rs.150 crore and above)—July, 2022", Ministry of Statistics and Programme Implementation, Government of India, July 2022, see http://www.cspm.gov.in/english/flr/FR_July_2022.pdf, accessed 27 August 2022.

192 - NPCIL, "Status of Projects Under Construction", Nuclear Power Corporation of India Limited, August 2022, see https://npcil.nic.in/content/297_1_ProjectConstructionStatus.aspx, accessed 27 August 2022.

Nuclear Intelligence Weekly reported that "Units 3 and 4 were targeted for commissioning in March and November 2023, but will now be completed in September 2024 and March 2025".[193]

The three PHWRs under construction are also delayed. Unit 4 of Kakrapar was to be commissioned in 2015, while the two Rajasthan units were to be commissioned in late 2016. The above-mentioned official update from July 2022 reports anticipated dates of commissioning of June 2023 for Kakrapar-4 and December 2023 for Rajasthan-7 and Rajasthan-8.[194] In April 2022, the Central Electricity Regulatory Commission approved a petition from NPCIL that anticipates Rajasthan-7 being synchronized with the grid only by June 2023.[195] According to a power ministry memo from May 2022, completion of Kakrapar-4 appears to have been pushed back to March 2024.[196] At the time of writing this, the NPCIL website only says "under review" for the expected dates of commercial operation for Kakrapar-3 and -4 and Rajasthan-7 and -8 projects.[197]

Finally, as has been the case for some years now, the PFBR is still the most delayed project. The latest "anticipated" date for commissioning the PFBR has been pushed back from October 2022, as reported in the last WNISR, to September 2024.[198] When construction started in 2004, the anticipation completion date was September 2010, and that has been pushed back little by little.[199]

The projected cost of the PFBR has also risen, from the initially anticipated Rs.34.9 billion[200] to Rs.75 billion as of July 2022.[201] The Kakrapar project, where Unit 3 has already been commissioned, is now projected to cost Rs.192.2 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.

Construction Plans and Reality

For nearly a decade now, there has been talk about a large number of new PHWRs. Back in 2014, soon after the national elections, the Indian government's spokesperson announced in the parliament that a number of reactors were to be launched by NPCIL. The wave of construction was to start in 2015 and included two 700 MW PHWRs each in Gorakhpur in Haryana state (GHAVP 1 & 2), Chutka in Madhya Pradhesh state (CMAPP 1 & 2), Mahi Banswara in Rajasthan

193 - Rakesh Sharma, "Kudankulam-5 Construction Start Marks New Milestone", *Nuclear Intelligence Weekly*, 2 July 2021.

194 - MoSPI, "440th Flash Report on Central Sector Projects (Rs.150 crore and above) – July 2022", 2022, op. cit.

195 - Central Electricity Regulator Commission, "Petition No. 112/MP/2022", filed by NPCIL Vs. Norther Regional Load Dispatch Centre, 22 April 2022, see https://cercind.gov.in/2022/orders/112-MP-2022.pdf, accessed 24 May 2022.

196 - Sudarshan Varadhan, "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 1 June 2022.

197 - NPCIL, "Status of Projects Under Construction", August 2022, op. cit.

198 - MoSPI, "440th Flash Report on Central Sector Projects (Rs.150 crore and above) – July 2022", 2022, op. cit.

199 - M. V. Ramana and Nidhi Sharma, "Problems with the Prototype Fast Breeder Reactor", *The India Forum*, 26 February 2021, see https://www.theindiaforum.in/article/problems-prototype-fast-breeder-reactor, accessed 6 March 2021.

200 - As of 1 July 2022, the conversion rate to US$ is around Rs.79 per U.S. dollar. However, the PFBR as other nuclear project cost estimates are in mixed-year Rupees and so directly converting it into other currencies using one conversion rate would be misleading.

201 - MoSPI, "440th Flash Report on Central Sector Projects (Rs.150 crore and above) – July 2022", 2022, op. cit.

state (Mahi Banswara 1 & 2), and Kaiga in Karnataka state (Kaiga 5 & 6).[202] The envisioned dates for "first pour of concrete" and "completion" were June 2015 and September 2020/March 2021 (for the two Gorakhpur units); June 2015 and December 2020/June 2021 (for the two Chutka units); June 2016 and December 2021/June 2022 (for the two Mahi Banswara units); and December 2016 and June 2022/December 2022 (for the two Kaiga units). None of those projects started construction by these planned dates.

Instead, in May 2017, the union cabinet approved the construction of ten more 700 MW PHWRs, at an estimated cost of 1.05 trillion Rupees, and the news was promoted widely by NPCIL as a "mega impetus for nuclear power".[203] In 2018, the list included the units mentioned earlier, but also two additional units at Gorakhpur (GHAVP 3 & 4) and Mahi Banswara (Mahi Banswara 3 & 4).[204] In other words, by that time, 12 new 700 MW units were promised.

It has been more than five years since that announcement and construction is yet to begin on any of these. The latest update is from March 2022, when Department of Atomic Energy officials reportedly told the science and technology committee of the Indian Parliament that "first concrete for Kaiga units 5 and 6 is expected in 2023, followed by Gorakhpur Haryana Anu Vidyut Praiyonjan units 3 and 4 and Mahi Banswara Rajasthan Atomic Power Projects units 1-4 in 2024 and Chutka Madhya Pradesh units 1 and 2 in 2025".[205]

The status of the first two units at Gorakhpur is ambiguous. The government has repeatedly listed these as "projects under construction", with the latest such announcement being made in the Indian Parliament on 31 March 2022.[206] According to that announcement, GHAVP-1 & -2 is expected to be complete in 2028. However, there is no evidence that the project's concrete pour for the base slab of the reactor building has taken place. In March 2022, the *Deccan Herald* newspaper reported that "NPCIL… didn't answer questions on why the construction of… GHAVP-1 and -2—the first two 700 MW units at Haryana—remained stalled".[207]

The other major element in India's nuclear plans, ever since the U.S.-India nuclear deal was negotiated between 2005 and 2008, has been to import reactors from the U.S. and France. The 2014-announcement in parliament mentioned above also included envisioned dates for

202 - Lok Sabha, "Unstarred Question No. 956—New Nuclear Reactors", Department of Atomic Energy, Government of India, answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, 16 July 2014, see https://dae.gov.in/writereaddata/parl/budget2014_2/lsus956.pdf, accessed 24 May 2022.

203 - NPCIL, "Mega Impetus for Nuclear Power – Cabinet approves 10 new indigenous Pressurised Heavy Water Reactors", 18 May 2017, see http://www.npcil.nic.in/pdf/news_18may2017_01.pdf, accessed 28 May 2017; also see M. V. Ramana and Suvrat Raju, "Old Plans, Ongoing Handouts, New Spin—Deciphering the Nuclear Construction Announcement", *Economic and Political Weekly*, Vol 52 Issue 24, 17 June 2017, see http://www.epw.in/journal/2017/24/web-exclusives/old-plans-ongoing-handouts-new-spin.html, accessed 17 June 2017.

204 - Rajya Sabha, "Unstarred Question No. 813—Construction of New PHWR", Department of Atomic Energy, Government of India, answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, March 2018, see http://dae.nic.in/writereaddata/parl/budget2018/rssq218.pdf, accessed 24 May 2022.

205 - Sarita C. Singh, "Beginning 2023, India to start building nuclear power plants in 'fleet mode'", *The Economic Times*, 27 March 2022, see https://economictimes.indiatimes.com/industry/energy/power/beginning-2023-india-to-start-building-nuclear-power-plants-in-fleet-mode/articleshow/90470373.cms; and *WNN*, "2023 construction start for Indian reactor fleet", 28 March 2022, see https://www.world-nuclear-news.org/Articles/2023-construction-start-for-Indian-reactor-fleet; both accessed 23 May 2022.

206 - Rajya Sabha, "Unstarred Question No. 3203—Status of Under Construction and Planned Nuclear Power Plants", Department of Atomic Energy, Government of India, answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, 31 March 2022, see http://dae.gov.in/writereaddata/rsusq3203.pdf, accessed 6 April 2022.

207 - Kalyan Ray, "Construction of 700 MW units at Kaiga nuclear plant may begin in 2023", *Deccan Herald*, 16 March 2022, see https://www.deccanherald.com/national/construction-of-700-mw-units-at-kaiga-nuclear-plant-may-begin-in-2023-1091908.html, accessed 25 May 2022.

"first pour of concrete" and "completion" for imported reactors: October 2015 and April 2021/April 2022 (for two 1650 MW EPR units from France to be built at Jaitapur in Maharashtra); June 2016 and October 2021/October 2022 (for two 1500 MW ESBWR [Economic Simplified Boiling Water Reactor] units from GE-Hitachi to be built in Kovvada in Andhra Pradesh), and June 2016 and December 2020/December 2021 (for two 1100 MW AP 1000 units from Westinghouse to be built in Chhaya Mithi Virdi in Gujarat).[208] However, no project has gone forward. In February 2022, when the government was asked in parliament about any additional capacity as a result of the nuclear deal, it simply stated "discussion[s] to arrive at project proposals (…) are in progress".[209]

Among the foreign vendors, only EDF appears to be making some progress, albeit slow, on a contract. In May 2022, EDF announced that it hopes to seal a deal "in the coming months".[210] But such announcements have been made before. In 2018, EDF reportedly submitted a techno-commercial proposal and there were media reports that construction was to commence "as soon as possible".[211] Two years earlier, in 2016, it was reported that an agreement was "due by year-end".[212] Given EDF's major cost-escalation experiences with EPR projects in Europe, it is unlikely that they would be able to make an attractive enough offer to offset the major economic disadvantages associated with EPRs in Jaitapur.[213]

The other two vendors—Westinghouse and GE-Hitachi—seem to be balking at the idea that they might be held liable for damages in the event of an accident. In September 2021, India's Foreign Secretary confirmed that talks with Westinghouse are continuing but admitted that some issues, including liability for accidents, are yet to be addressed.[214] GE-Hitachi has flatly refused to sell reactors to India because of its concern about liability.[215]

In fact, the problem has less to do with the amount vendors would be liable for, which is but a small fraction of the cost of these reactors; rather, these vendors seem to be opposing the principle that they might be asked to compensate victims in the event that their supposedly

208 - Lok Sabha, "Unstarred Question No. 956—New Nuclear Reactors", Government of India, July 2014, op. cit.

209 - Rajya Sabha, "Unstarred question No. 167—Indo-US nuclear deal", Department of Atomic Energy, Government of India, answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, 3 February 2022, see https://dae.gov.in/writereaddata/rsusq167.pdf, accessed 20 February 2022.

210 - Dominique Vidalon, "EDF hopes to seal EPR nuclear reactor deal in India in coming months", *Reuters*, 5 May 2022, see https://www.reuters.com/world/india/edf-hopes-seal-epr-nuclear-reactor-deal-india-coming-months-2022-05-05/, accessed 29 May 2022.

211 - *Business Today*, "France submits techno-commercial offer for Jaitapur nuclear power project", 24 December 2018, see https://www.businesstoday.in/top-story/france-submits-techno-commercial-offer-for-jaitapur-nuclear-power-project/story/303697.html, accessed 25 December 2018; and *The Hindu*, "France, India working on Jaitapur nuclear power project", 15 December 2018, see https://www.thehindu.com/news/national/france-india-working-on-jaitapur-nuclear-power-project/article25753453.ece, accessed 23 June 2019.

212 - *WNN*, "Jaitapur agreement due by year-end", 25 January 2016, see http://www.world-nuclear-news.org/NN-Jaitapur-agreement-due-by-year-end-2501165.html, accessed 27 May 2016.

213 - Suvrat Raju and M. V. Ramana, "Cost of electricity from the Jaitapur Nuclear Power Plant", *Economic and Political Weekly*, 29 June 2013.

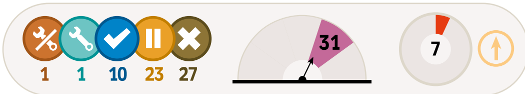
214 - Huma Siddiqui, "Liability clause holds up the Westinghouse & NPCIL nuclear reactors", *Financial Express*, 23 September 2021, see https://www.financialexpress.com/defence/liability-clause-holds-up-the-westinghouse-npcil-nuclear-reactors/2336246/, accessed 29 May 2022.

215 - *Press Trust of India*, "GE says no to nuclear power plants in India, cites liability risks", as published on *DNA India*, 20 March 2018, see https://www.dnaindia.com/business/report-ge-says-no-to-nuclear-power-plants-in-india-cites-liability-risks-2127340, accessed 29 May 2022.

safe reactors do actually undergo a severe accident.[216] Unless India's parliament undoes the liability provisions, which is unlikely, the possibility of importing reactors from U.S. vendors appears remote.

None of this is new for India's nuclear program. Its history has been full of overly ambitious announcements that have never materialized, despite ample financial and political support from parties across the spectrum.[217]

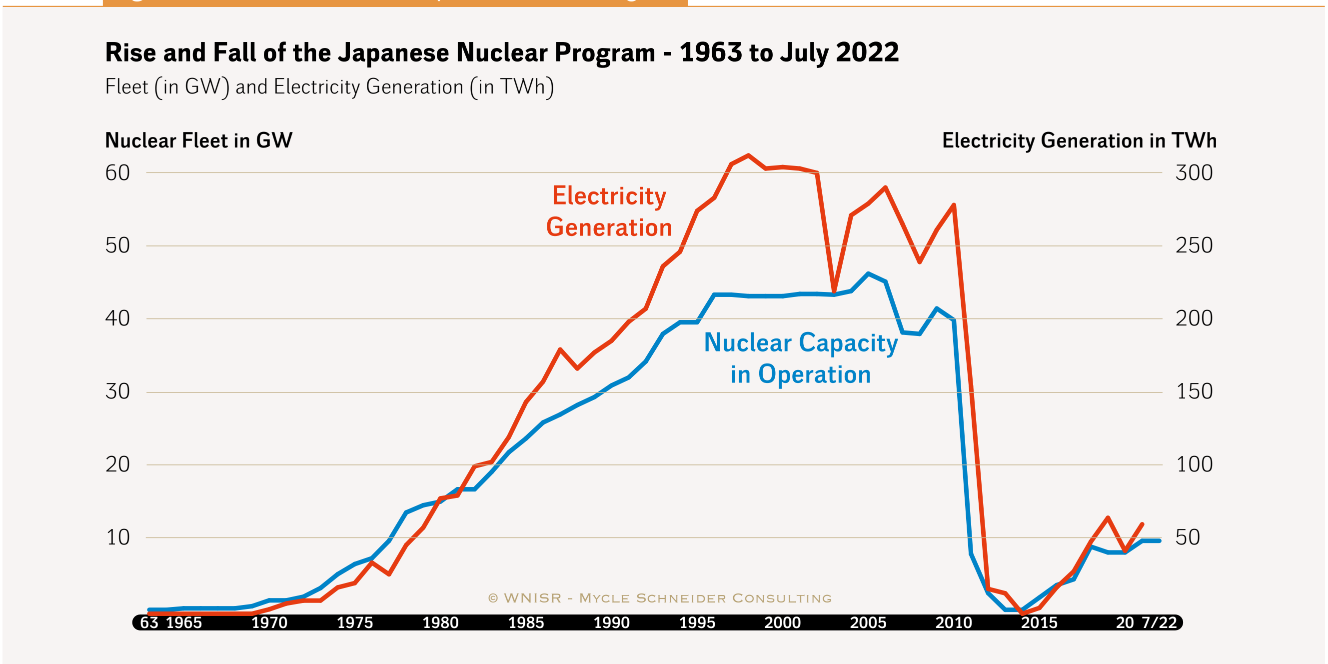
JAPAN FOCUS



Overview

In Financial Year 2021 (April 2021–March 2022), the number of "operable" nuclear reactors in Japan remained stable at only ten with a capacity of just under 10 GWe. The average capacity factor has improved from 15.5 percent in FY 2020 to 21.1 percent in FY 2021. As a result, nuclear power generation increased from 38.8 TWh to 67.8 TWh, and its share in total power generation doubled from 3.9 percent to 7.9 percent. The respective numbers for the calendar years are a growth from 43.1 TWh representing a share 5.1 percent in 2020 to 61.3 TWh and 7.2 percent in 2021. (See Figure 34).

Figure 34 · Rise and Fall of the Japanese Nuclear Program



Sources: WNISR with IAEA-PRIS, 2022

216 - 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, accessed 16 February 2015; 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; also Athena Kerins and M. V. Ramana, "Liability for nuclear accidents: Whose interests are served?", in "Conserve for Future", ed. by K. Sudha, Damodaram Sanjivayya National Law University, 2021.

217 - M. V. Ramana, "The Power of Promise—Examining Nuclear Energy in India", *Penguin Books*, December 2012.

As of 25 July 2022, only seven of the ten operable reactors (Takahama-3, Ohi-3 & -4, Ikata-3, Genkai-4, Sendai-1 & -2) were actually operating. No new operating license was issued during the past year. A total of 33 units (33.1 GWe) are still officially in "commercial operation" status, out of which 25 units (24.8 GWe) have applied for an operating license, with 17 approved so far, of which 10 have restarted at some point.[218]

Eleven years after the Fukushima disaster began, reactors now operating are all PWRs although the Nuclear Regulation Authority (NRA) confirmed that five BWRs (Kashiwazaki Kariwa-6 and -7, Tokai-2, Onagawa-2, and Shimane-2) were meeting the new regulatory requirements set in 2013. Tokyo Electric Power Co.'s (TEPCO) Kashiwazaki Kariwa units were the first BWRs which received approval from NRA on 27 December 2017. However, due to the lack of approval from Niigata Prefecture and a nuclear security violation in 2021, it is not known when the reactors will restart operating.[219] Japan Atomic Power Co's (JAPCO) Tokai-2 was the first BWR to get lifetime-extension approval from NRA on 7 November 2018. Actual restart operation has been postponed until 2024 or later because of ongoing work on additional safety measures including the installation of a Specialized Safety Facility (SFF) against terrorist attacks. Onagawa-2 received approval from NRA on 26 February 2020 but work on additional safety measures will not be completed until November 2023 with power generation thought to resume in February 2024.[220] Chugoku Electric Power Co's Shimane-2 received approval from NRA on 15 September 2021 but negotiations with local governments continued until 2 June 2022 when the Governor of Shimane Prefecture, Tatsuya Maruyama, agreed to the restart of the unit. It is now expected that Shimane-2 will be reconnected to the grid sometime in 2023.[221]

Kansai Electric Power Co (KEPCO) has the largest number of reactors (seven in total, all PWRs) but only three of them (Takahama-3, Ohi-3 and -4) are currently operating (as of July 2022). Takahama-3 was shut down on 1 March 2022 for periodic inspections when damaged steam generator tubes were identified, and restart of operation was postponed. It was reported that Takahama-3 finally started operation on 24 July 2022, after damages were repaired.[222] For both Ohi-3 and -4, the deadline for completion of the SSF against terrorist attacks is 24 August 2022. They received the construction permit for SSFs in August 2021, but while Ohi-4 will likely meet the deadline, it is not the case for Ohi-3. Therefore, it is expected that Ohi-3 will need to be shut down after 24 August 2022 and restart 18 December 2022.[223] Although there was an unprecedented court decision not to start operation of Ohi-3 and -4 in December 2020,[224]

218 - JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 7 July 2022, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2022/07/jp-npps-operation20220707_en.pdf; also available in Japanese, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2022/07/jp-npps-operation20220707.pdf; both accessed 25 July 2022.

219 - Ibidem; and *WNN*, "Security lapses impact Kashiwazaki-Kariwa restart", 17 March 2021, see https://world-nuclear-news.org/Articles/Security-lapses-impact-Kashiwazaki-Kariwa-restart, accessed 19 August 2022.

220 - JAIF, "Current Status of Nuclear Power Plants in Japan", as of 7 July 2022, op. cit.

221 - Ibidem, and The Asahi Shimbun, "Governor of Shimane agrees to restart idled nuclear reactor", 2 June 2022, see https://www.asahi.com/ajw/articles/14635842, accessed 25 July 2022.

222 - *NHK News*, "Kansai Denryoku Takahama 3 Go-ki Fukkyu Sagyo Oe Kyo Unten Saikai" ["Kansai Electric Power's Takahama-3 will start its operation today after reparation work"], 24 July 2022 (in Japanese), see https://www3.nhk.or.jp/lnews/fukui/20220724/3050011877.html, accessed 25 July 2022.

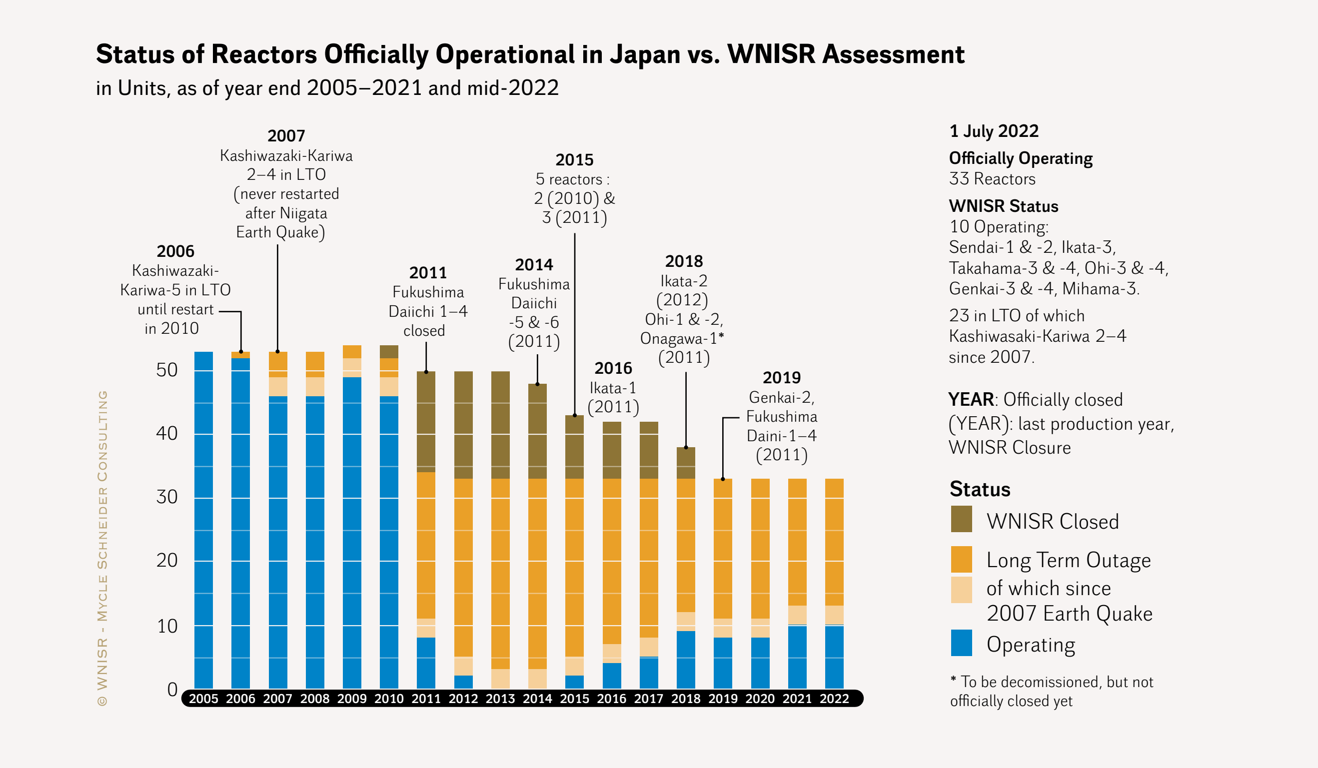
223 - Chunichi Shimbun, "Oi Genpatsu 3 go-ki ga 12 gatsu 18 nichi hasso-den, tosho yori 4nichi hayameru" ["Ohi-3 will start its operation on December 18, 2022, 4 days earlier than planned"], 23 July 2022, see https://www.chunichi.co.jp/article/513284, accessed 25 July 2022.

224 - *Nikkei Asia*, "Japan court nullifies approval of Oi nuclear reactor safety steps", 4 December 2020, see https://asia.nikkei.com/Business/Energy/Japan-court-nullifies-approval-of-Oi-nuclear-reactor-safety-steps, accessed 25 July 2022.

Kansai Electric Power immediately appealed the upper court and thus they were allowed to operate the reactors at least until the final ruling is made.[225]

Shikoku Electric Power's Ikata-3 restarted operation on 2 December 2021, after an outage of close to two years. The unit had been taken offline in December 2019 to undergo refueling and maintenance, when it met with a series of incidents in January 2020, the first involving control rods during spent fuel removal, another one a brief loss of power.[226] In January 2021, Hiroshima High Court decided not to allow the restart of Ikata-3, but later overturned its ruling in March 2021[227] and then denied the injunction appeal on 4 November 2021 (see legal cases section). Ikata-3 did not restart immediately, however, due to delays in SSF construction and a safety violation incident (an emergency operator illegally left his position without permission). The SSF was finally completed in October 2021, and the reactor was allowed to restart on 6 December 2021, resuming commercial operation on 24 January 2022.[228]

Figure 35 · Status of the Japanese Reactor Fleet



Sources: Various, compiled by WNISR, 2022

Kyushu Electric Power Co's Genkai-3 was shut down in January 2022, and the operator will not meet the deadline of SSF construction of 24 August 2022. The unit is expected to

225 - *Tokyo Shimbun*, "Kanden wa Oi-Genpatsu 3,4 go-ki no unten keizoku-e, secchi kyoka torikeshi no Osaka chisai hanketsu niwa koso hoshin" ["KEPCO will continue to operate Ohi-3 and 4 as they plan to appeal the Osaka regional court decision"], 7 December 2020, see https://www.tokyo-np.co.jp/article/72923, accessed 25 July 2022.

226 - Shota Ushio and Yuzo Yamaguchi, "NRA will not 'intervene' in safety issues at Shikoku Electric's Ikata: Fuketa", *Platts Inside NRC*, S&P Global, 3 February 2020; and Kyodo News, "Spent MOX fuel removed at Ikata nuclear plant, 1st time in Japan", 14 January 2020, see https://english.kyodonews.net/news/2020/01/c6c067292f23-spent-mox-fuel-removed-at-ikata-nuclear-plant-1st-time-in-japan.html, accessed 19 August 2022.

227 - David Dalton, "Japan/Court Overturns Decision to Suspend Operation of Ikata-3", *NucNet*, 18 March 2021.

228 - JAIF, "Current Status of Nuclear Power Plants in Japan", July 2022, op. cit.

restart in January 2023. Genkai-4 was shut down on 30 April 2022 for regular inspection and restarted on 13 July 2022.[229] But again due to delays in construction of SSF whose deadline is 13 September 2022, it will be taken off the grid again then. It is currently expected to restart in February 2023.[230] Sendai-1 and -2 were shut down for inspection in October 2021 and 13 June 2022 respectively. Unit 1 restarted on 20 December 2021, Unit 2 on 13 June 2022 and both remain online as of July 2022.[231] Both units, 39 and 37 years old respectively, are preparing for license extension beyond 40 years.

No additional reactors have been declared for permanent closure during the past year,[232] thus the total remains unchanged at 27 reactors (21 reactors after the Fukushima accident, including the ten at Fukushima Daiichi & Daini). (See Figure 35 and Table 6).

Legal Cases Against the Restart of Existing Reactors

Like the year 2020–2021, the year since mid-2021 witnessed significant rulings from courts across Japan that underscore the continuing uncertainties for future reactor operation, as well as highlighting some of the underlying safety issues that remain unresolved. The following cases do not include the important decisions on the Fukushima disaster that are discussed in the Fukushima Status Report.

"The plant does not have adequate protection against a tsunami."

The court decision made by the Sapporo District Court on Hokkaido Electric Power Co.'s Tomari nuclear plant on 31 May 2022, was probably the most important one made in the past year. It is a somewhat unusual case as the safety licensing process is still underway, and typically legal challenges are launched against licensing decisions made by the NRA. The case was filed in November 2011 by over 1,000 plaintiffs against Hokkaido Electric Power Co. The Sapporo District Court ruled that the utility company should not resume operation of all three reactors at its Tomari nuclear plant in Hokkaido but rejected the request to decommission the plant. The reactors were all shut down for regular inspections by May 2012, and the utility was applying for a license to restart the units by meeting the new regulatory requirements made by the NRA. The presiding judge Tetsuya Taniguchi said that the power company had "not provided evidence of the safety of spent nuclear fuel stored at the plant and the plant does not have adequate protection against a tsunami", ruling that 44 of the plaintiffs who live within a 30-km radius would be seriously affected by a severe accident "and have their human rights hindered". The Hokkaido utility said that it will appeal the case.[233]

Two other cases resulted in injunctions against operating nuclear power plants being rejected. On 4 November 2021, the Hiroshima district court ruled against injunctions on the Ikata

229 - *Kyodo News*, "Kyuden, Genkai 4 go-ki no hatsuden saikai, Jyukyu hippaku ni taio" ["Kyushu Electric Power started its Genkai-4, responding to tight demand/supply condition"], 13 July 2022 (in Japanese), see https://news.yahoo.co.jp/articles/4a27a8e5063dee0e5e4c238fe264a14f0b4ee132, accessed 25 July 2022.

230 - JAIF, "Current Status of Nuclear Power Plants in Japan", July 2022, op. cit.

231 - *NHK News*, "Sendai Genpatsu 2 go-ki 11 nichi kido shi, 13 nichi ni hatsuden kaishi e, Kyuden happyo" ["Kyushu Electric said Sendai 2 will start its operation on 11th and start power generation on 13th"], 7 June 2022 (in Japanese), see https://www3.nhk.or.jp/lnews/kagoshima/20220607/5050018970.html, accessed 25 July 2022; and JAIF, July 2022, op. cit.

232 - JAIF, "Current Status of Nuclear Power Plants in Japan", July 2022, op. cit. 27 reactors in total including JPDR, Fugen, Monju.

233 - *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.

nuclear power plant.[234] The court ruled that the evidence provided by the plaintiffs over the risk of an accident caused by potential earthquakes were not sufficient. The only unit that has not been permanently shut down is Unit 3, which resumed commercial operation in January 2022. On 10 March 2022, the Nagoya regional court ruled against plaintiffs requesting an injunction against Kansai Electric Power Co's (KEPCO) Takahama nuclear plant.[235] On 9 March 2016, the Otsu district court had issued an injunction against the operation of Takahama-3 and -4, but the Osaka Hight Court lifted the injunction on 28 March 2017.[236] (see dedicated section in WNISR2021).

The Kashiwazaki Kariwa Safety/Security Affair

A serious breach of nuclear security regulations occurred in 2020 at Kashiwazaki Kariwa plant in Niigata Prefecture. The unauthorized entry by employees into the central control room and inadequate management of security related equipment which detect intrusion of outsiders resulted in NRA's decision to prohibit TEPCO to load fresh nuclear fuel at the plant in April 2021.[237] (See detailed account in WNISR2021.) On 27 April 2022, NRA published its interim report on the Kashiwazaki Kariwa security issue in which they investigated enhanced nuclear security measures taken by TEPCO and made a series of recommendations to be implemented by the operator.[238]

On 25 July 2022, an independent Expert Commission on the Assessment of Nuclear Security submitted its first report to TEPCO.[239] The Commission was appointed by TEPCO to evaluate nuclear security measures at their facilities in December 2021. This is one of the measures which TEPCO promised to take in its own assessment report submitted to NRA on 22 September 2021.[240] The report concluded that improvement of security measures is steadily progressing, but it noted that in May 2021 employees received an expired site access badge. Isao Itabashi, director of the Research Center for Public Policy Investigation Committee and the chair of the Expert Commission, said, "The improvement is progressing, but there are many points to be strengthened. It is necessary to continue the investigation until the culture

234 - Datsu Genpatsu Bengo-dan Zenkoku Renraku Kai, "Ikata Genpatsu Teishi Mitomezu" ["Court ruled not allowing injunction of Ikata nuclear plant"], National Liaison Group of Lawyers for Nuclear Phase-out, 4 November 2021 (in Japanese), see http://www.datsugenpatsu.org/bengodan/judgment/21-11-4/, accessed 26 July 2022.

235 - Datsu Genpatsu Bengo-dan Zenkoku Renraku Kai, "Futo Hanketsu: Takahama Teishi Gimuzuke sosho seikyu kikyaku ["Unfair judge: appeal to legally requiring injunction of Takahama nuclear plant was rejected"], National Liaison Group of Lawyers for Nuclear Phase-out, 10 March 2022, see http://www.datsugenpatsu.org/bengodan/news/22-3-10/, accessed 26 July 2022.

236 - WNISR, "Japan: Court Overturns Injunction Against Operation of Takahama-3 and 4", 29 March 2017, see https://www.worldnuclearreport.org/Japan-Court-Overturns-Injunction-Against-Operation-of-Takahama-3-and-4.html, accessed 21 August 2022.

237 - Osamu Tsukimori, "Tepco lapse a wake-up call for Japan's nuclear security protocols, expert says", *The Japan Times*, 15 April 2021, see https://www.japantimes.co.jp/news/2021/04/15/national/nra-niigata-tepco-nuclear-security/, accessed 26 July 2022

238 - NRA, "Tokyo Denryoku Kashiwazaki-Kariwa Genshiryoku Hatsudensho ni Okeru ID ka-do fuseisiyou jian oyobi Kaku bussitsu bougo setsubi no kino no ichibu sousitsu jian ni taisuru tuika tensa no chukan torimatome" ["Interim Report on Additional Inspection of Issues Regarding Illegal Use of ID Card and Loss of Function of Nuclear Material Protection Equipment at Kashiwazaki Kariwa Plant"], Nuclear Regulation Authority, 27 April 2022, see https://www.nsr.go.jp/data/000388647.pdf, accessed 26 July 2022.

239 - Kaku Sekyuriti Senmonka Hyoka Iinkai, "Tokyo Denryoku ni Okeru Kaku Sekyuriti ni Kansuru Hyoka Houkokusho-Dai 1kai Houkoku" ["Assessment Report on Nuclear Security at Tokyo Electric Power Co.: 1st Report"], Expert Committee on Assessment of Nuclear Security, 25 July 2022, see https://www.tepco.co.jp/press/news/2022/pdf/220725a.pdf, accessed 26 July 2022.

240 - TEPCO, "Kashiwazaki Kariwa Gennshiryoku Hatsudennsho No ID ka-do fusei shiyo oyobi kaku busshitsu bogo setsubi no kino no ichibu soshitsu ni kakawaru kaizen sochi houkoku nit suite ["Regarding Improvement Measures on illegal use of ID Card and a Loss of Function of Equipment for Nuclear Materials Protection at Kashiwazaki Kariwa Nuclear Power Plant"], 22 September 2021, see https://www.tepco.co.jp/press/release/2021/1642625_8711.html, accessed 28 July 2022.

of nuclear security is rooted company-wide." The Commission is expected to continue its investigation and make reports and recommendations semi-annually.[241]

Reactor Closures and Spent Fuel Management

No additional reactors were formally declared for decommissioning in the year to 7 July 2022. The 11 commercial Japanese reactors now confirmed to be decommissioned—not including the Monju Fast Breeder Reactor (FBR) or the ten Fukushima reactors—had a total generating capacity of 6.4 GW, representing about 15 percent of Japan's operating nuclear capacity as of March 2011.[242] Together with the ten Fukushima units, the total rises to 21 reactors and 15.2 GW or just under 35 percent of nuclear capacity prior to 3/11 that has now been permanently removed from operations (see Figure 35 and Table 6).

Regarding spent fuel from research reactors—such as Fugen, a 165 MWe Advanced Thermal Reactor or ATR, that first reached criticality in 1978 and was closed in 2003, and Monju, a 280 MWe FBR, that first reached criticality in 1994, was connected to the grid in August 1995 and produced its last electricity in December 1995 but was officially closed only in 2017—Japan's basic policy is still the reprocessing of all spent fuels from those reactors. Although, there are no specific plans to use the separated plutonium.

By 22 April 2022, all spent fuel from Monju had been moved to a temporary storage tank filled with liquid sodium and transfer to a pool storage cooled with water was scheduled to start "after June". Japan Atomic Energy Agency (JAEA), which manages decommissioning work of Monju, plans to complete the spent fuel transfer by the end of the year, start the extraction of the liquid sodium in 2023, and then, eventually, ship all spent fuels to France for reprocessing. Shipment is expected to be completed in 2037.[243]

241 - *NHK News*, "Counterterrorism Countermeasures at Kashiwazaki-Kariwa Nuclear Power Plant Further Improvement Request Report TEPCO Third Party Committee", as published on *Teller Report*, 25 July 2022, see https://www.tellerreport.com/life/2022-07-25-counterterrorism-countermeasures-at-kashiwazaki-kariwa-nuclear-power-plant-further-improvement-request-report-tepco-third-party-committee.ByH_7zG229.html, accessed 26 July 2022.

242 - Based on a total installed capacity of 43.6 GW (not including the 246 MW Monju FBR and Kashiwazaki Kariwa 2–4) which were in LTO in March 2011.

243 - *NHK News*, "Monju decommissioning work Completed moving to temporary storage location for nuclear fuel in the reactor", as published on *Teller Report*, 22 April 2022, see https://www.tellerreport.com/life/2022-04-22-monju-decommissioning-work-completed-moving-to-temporary-storage-location-for-nuclear-fuel-in-the-reactor.SkxUuezeSq.html, accessed 27 July 2022.

Table 6 – Official Reactor Closures Post-3/11 in Japan (as of 1 July 2022)

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, Japan Nuclear Safety Institute, compiled by WNISR, 2011–2022

Notes

BWR: Boiling Water Reactor; **PWR**: Pressurized Water Reactor; **FBR**: Fast Breeder Reactor; **LTS**: Long-Term Shutdown.
JAEA: Japan Atomic Energy Commission; **JAPC**: Japan Atomic Power Company

(a) – Unless otherwise specified, all announcement dates from Japan Nuclear Safety Institute, "Licensing status for the Japanese nuclear facilities", 26 February 2020, see http://www.genanshin.jp/english/facility/map/, 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", 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.

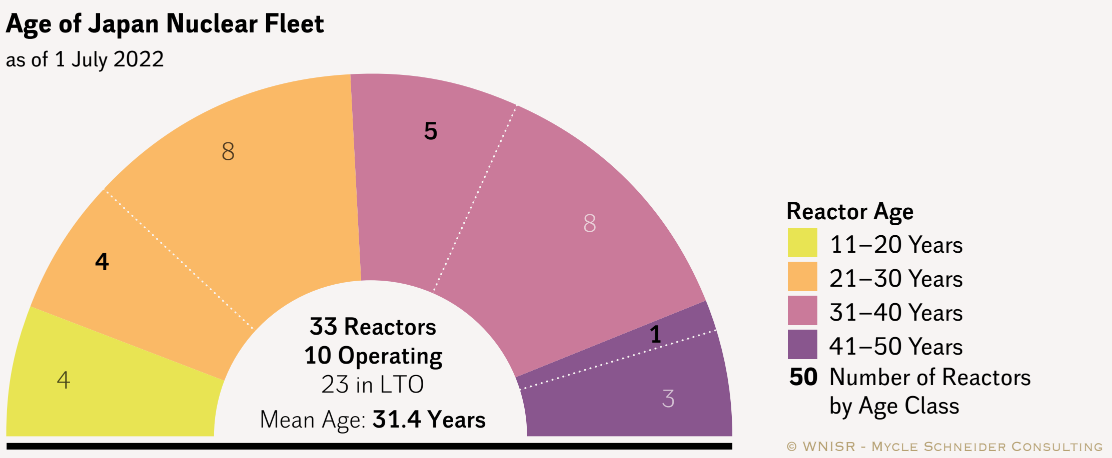
(g) – Date from IAEA-PRIS. (No official closure date in according to JAIF).

On 24 June 2022, it was reported that JAEA had negotiated a contract with French nuclear fuel company Orano for the transport and reprocessing of all spent fuel (731 fuel assemblies) from Fugen. JAEA originally gave a contract to Orano in November 2018 to carry out preparatory work for shipment of the Fugen spent fuel to France. Under the new contract, which is reported to be worth €250 million (US$$_{2022}$268 million), Orano will also be in charge of MOX fabrication and the reuse of separated Japanese plutonium in French reactors for power generation. Therefore, separated plutonium from reprocessing will not return to Japan, while wastes generated from reprocessing will be shipped back. This is the first such contract in which separated plutonium, which officially is considered an important energy resource in Japan, will not be returned to Japan. It is likely that JAEA will *pay* Orano for keeping the plutonium as the material usually has a zero-book-value and a negative market value.

Orano is also responsible for design and fabrication of transport casks, and the execution of shipments, which are scheduled to take place between 2023 and 2026.[244]

As of mid-2022, the Japanese nuclear fleet of 33 units, including 23 in LTO, had reached a mean age of 31.4 years, with 17 units over 31 years (see Figure 36).

Figure 36 · Age Distribution of the Japanese Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2022

Energy Policy and the Role of Nuclear Energy

Japan's latest Strategic Energy Plan (SEP), also called the Basic Energy Plan, was published in October 2021.[245] The biggest difference from the previous Strategic Energy Plan published in July 2018[246] is the introduction of a new policy goal of "carbon neutrality by 2050". It naturally emphasizes the importance of renewable energy sources, but utilization of nuclear power is included as an option to achieve the goal. However, the basic policy of "reducing its dependence

244 - *WNN*, "Orano contracted to reprocess Fugen used fuel", 28 June 2022, see https://www.world-nuclear-news.org/Articles/Orano-contracted-to-reprocess-Fugen-used-fuel, accessed 27 July 2022; and 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, accessed 28 June 2022.

245 - Agency for Natural Resources and Energy, "Outline of Strategic Energy Plan", Ministry of Economy, Trade and Industry, October 2021, see https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf; see also full text in Japanese, see Agency for Natural Resources and Energy, "Enerugī kihon keikaku" ["Basic Energy Plan"], METI, October 2021, see https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/20211022_01.pdf; both accessed 27 July 2022.

246 - METI, "Strategic Energy Plan", Ministry of Economy, Trade and Industry, Government of Japan, July 2018, see https://www.enecho.meti.go.jp/en/category/others/basic_plan/5th/pdf/strategic_energy_plan.pdf, accessed 27 July 2022.

on nuclear power as much as possible" remains unchanged, and there is no explicit mentioning of building new nuclear power plants.

Here are some important quotes concerning nuclear targets from the Strategic Energy Plan of 2021:[247]

> We will address maximum introduction of renewable energy as major power sources on the top priority....and necessary amount of nuclear power will be continuously utilized on the major premise of ensuring safety and public trust. (...)
>
> Restart of operation with safety as top priority: launch of restart acceleration task force; bringing human resources and knowledges together; and maintaining and improving technological capability.
>
> Measures for spent nuclear fuel: promotion of construction/utilization of interim storage facilities and dry storage facilities, etc. to increase storage capacity; and technology development for reducing the volume and harmfulness of radioactive waste.
>
> Nuclear fuel cycle: makes efforts towards the completion and operation of Rokkasho Reprocessing Plant by public and private partnership obtaining understanding of relevant municipalities involved and international society; and further promotion of plutonium-thermal (MOX [Mixed Oxide] fueled) power generation.
>
> (...) development of fast reactor will be steadily promoted by utilizing international cooperation;[248] small modular reactor [SMR] technology will be demonstrated through international cooperation, and component technologies related to hydrogen production at high temperature gas-cooled reactor will be established, as well as R&D [Research and Development] of nuclear fusion will be promoted through international collaboration as ITER Project, etc.

The targeted share of nuclear power by 2030 remains the same as in the previous plan, that is 20–22 percent of total power generation, while the target for the renewable energy share has been increased to 36–38 percent compared with 22–24 percent in the previous plan. The target shares for various fossil fuels were lowered compared to the previous plan: for LNG from 27 percent to 20 percent, and for coal from 26 percent to 19 percent.[249]

Impact of Ukraine Crisis on Nuclear Power Debate

The impact of the Ukraine crisis on the debate about energy and nuclear policy in Japan has been quite significant. Japan has a significant reliance on LNG, including about 9 percent from Russia (in 2021).[250]

247 - METI, "Outline of Strategic Energy Plan", October 2021, op. cit.

248 - On 26 January 2022, JAEA, Mitsubishi Heavy Industry (MHI) and Mitsubishi FBR Systems announced that they signed a Memorandum of Understanding (MOU) with Terra Power of the US to cooperate on the development of sodium-cooled fast reactor, called "Natrium". See *WNN*, "US, Japanese firms agree to cooperate on fast reactors", 27 January 2022, see https://www.world-nuclear-news.org/Articles/US,-Japanese-firms-agree-to-cooperate-on-fast-reac, accessed 27 July 2022.

249 - It assumes total electricity generation will reduce to 934 TWh from current 1,065 TWh, and greenhouse gas reduction rate will improve from 14% in the previous plan to 26% in the new plan.

250 - S&P Global: "Japan eyes operating up to 9 nuclear reactors from current 5 by winter: METI minister", 15 July 2022.

Russian attacks against civilian nuclear facilities, including Chernobyl and Zaporizhzhia nuclear power plants, raised serious safety and security concerns over Japanese nuclear facilities. On 8 March 2022, the Governor of Fukui Prefecture, which hosts 15 reactors, met with Defense Minister Nobuo Kishi and asked for tighter defense over nuclear facilities in the prefecture requesting to deploy the Self-Defense Forces in the region where a large number of nuclear plants are located.[251]

On 30 March 2022, the National Governors' Association issued an emergency request to the government which includes the following points:[252]

- The government should deter such military attack and invasion of other countries' territories through diplomatic channels;
- order nuclear utilities to shut down all nuclear reactors when such military attacks are imminent; and
- in case missile attacks against nuclear power plants are imminent, take all necessary measures, including missile defense by Self-Defense Forces.

Other pre-eminent policy issues are higher electricity prices as well as possible power shortages in Japan. Due to higher fossil fuel prices, even prior to the price rises caused by the Ukrainian crisis, Japan's spot power price rose to more than double the five-year average. According to the Japan Electricity Power Exchange, the average wholesale day-ahead price was JP¥15.47/kWh (US$0.11/kWh) on 18 April 2022, up 26 percent over the previous week.[253]

On 22 March 2022, METI and TEPCO warned of a possible power outage in the areas serviced by TEPCO and Tohoku Electric Power Co, potentially affecting around 2–3 million households, as some power plants remained offline following a powerful earthquake in the Tohoku area and lower than expected power savings. Later, METI reported nevertheless that significant decline in power consumption helped to avoid a power outage.[254] On 26 June 2022, METI again warned that the power supply situation would be very tight in the area of Tokyo, asking for energy conservation by citizens and industry.[255] And on 30 June 2022, the Government still maintained power shortage advisory for the fourth straight day as severe summer heat conditions continued.[256]

Although it is not clear that restarting nuclear power would help the tight energy situation better than other options, public opinion gradually shifted in favor of restarting idled nuclear power plants. According to *Jiji Press* polling released on 21 July 2022, 48.4 percent of the 2,000 respondents were in favor of restarting reactors whose safety has been confirmed

251 - *Nikkei Asia*, "Japan Weighs deploying Self-Defense Forces to guard nuclear plants", 18 March 2022, see https://asia.nikkei.com/Politics/Ukraine-war/Japan-weighs-deploying-Self-Defense-Forces-to-guard-nuclear-plants accessed 27 July 2022.

252 - *NHK News*, "Zenkoku Chijikai 'Kokunai no Genpatsu Kogeki eno Sonae Tettei O: Kuni ni Kinkyu Yosei" ["Japan's National Governors' Association issued an emergency request to the Government for 'protection of nuclear plants against military attack'"], 30 March 2022, see https://www.nhk.or.jp/politics/articles/lastweek/80186.html, accessed 27 July 2022

253 - Shoko Oda, "Japan Power Prices Rise as More Utilities Decline New Customers", *Bloomberg News*, 18 April 2022, see https://www.bloomberg.com/news/articles/2022-04-18/japan-power-prices-rise-as-more-utilities-decline-new-customers, accessed 27 July 2022.

254 - *Kyodo News*, "Power supply on tightrope in Tokyo, 15 other areas after quake", 22 March 2022, see https://english.kyodonews.net/news/2022/03/330a6c8e735b-tokyo-8-other-prefs-urged-to-save-power-as-demand-outstrips-supply.html, accessed 27 July 2022.

255 - Daniel Leussink, "Japan issues warning over possible power crunch on Monday", *Reuters*, 26 June 2022, see https://www.reuters.com/business/energy/japan-issues-warning-over-possible-power-crunch-monday-2022-06-26/, accessed 27 July 2022.

256 - *NHK News*, "Power shortage advisory for greater Tokyo continues on Thursday", 30 June 2022, see https://www3.nhk.or.jp/nhkworld/en/news/20220630_13/, accessed 27 July 2022.

while 27.9 percent of respondents were opposed to restarts.[257] The shift was documented in further surveys carried out by media outlets since the beginning of the war in Ukraine, as in March 2022, *Nikkei* reported that more than half of respondents supported a restart of the reactors (53 percent), and in June *Mainichi Shimbun* found that 47 percent of respondents were in favor of a restart and 30 percent opposed it, in early 2018 the same survey showed only 32 percent in favor and 48 percent against.[258]

Given this background, Prime Minister Kishida announced on 14 July 2022, that he had asked METI to have up to nine nuclear reactors operational this winter.[259] Although METI has no legal power to push NRA to accelerate the licensing process, some see this as a sign of the Japanese government's commitment to counter power shortage as well as to regain the role of nuclear power in carbon neutrality policy. On August 24, 2022, Prime Minister Kishida, in his speech at the GX (Green Transformation) Council, stated that the government should consider building a new generation of nuclear reactor.[260] Although this has been interpreted as a "new phase" of Japan's nuclear energy policy, PM Kishida confirmed again at the press conference on 31 August 2022, that the policy of "reducing dependence on nuclear power as much as possible" remained unchanged.[261]

Prospects for Nuclear Power

Given the tight power supply situations and higher electricity prices, the argument for the restart of existing reactors may have some positive impacts on public opinion, at least in short term. Due to the declining economic competitiveness of nuclear power, longer term prospects for nuclear power are still highly uncertain. Carbon neutrality policy may encourage nuclear power further, but the unfavorable environment surrounding nuclear power will not change dramatically.

In addition, many difficult issues facing the nuclear industry stem from the legacy of the Fukushima disaster. Notably, decommissioning of the Fukushima reactors and compensation issues are the most important matters that will not be resolved for a long time. Furthermore, spent fuel and waste disposal issues remain unsolved. A brighter future for nuclear power in Japan is not on the horizon.

257 - *Jiji Press*, "Nearly Half in Japan Support N-Reactor Restart: Jiji Poll", 21 July 2022, see https://jen.jiji.com/jc/eng?g=eco&k=2022072100800, accessed 22 August 2022.

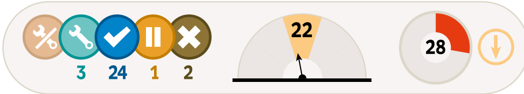
258 - Will Fee, "Local Opposition and Regulations Slow Japan's Return to Nuclear", *The Japan Times*, 26 May 2022.

259 - Elaine Lies, "Japan PM Kishida: asked industry minister to have up to 9 nuclear reactors operational this winter", *Reuters*, 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.

260 - *Nikkei Asia*, "Japan PM Kishida orders new nuclear power plant construction: Major shift in energy policy would focus on next-generation types of facilities", 24 August 2022. https://asia.nikkei.com/Politics/Japan-PM-Kishida-orders-new-nuclear-power-plant-construction, accessed 17 September 2022

261 - Peter Landers, "Japan's Kishida Says He Wants to Reduce Reliance on Nuclear Power as Much as Possible: Prime Minister leaves open possibility of studying new plants", August 31, 2022. https://www.wsj.com/articles/japans-kishida-says-he-wants-to-reduce-reliance-on-nuclear-power-as-much-as-possible-11661928640, accessed 17 September 2022.

SOUTH KOREA FOCUS



The Republic of Korea (South Korea) operates 24 reactors and has three reactors under construction. Hanbit-4 is in Long-Term Outage (LTO) because it has been shut down since May 2017 mainly due to 140 voids found in concrete containment walls and corrosion on containment liner plates.

President Yoon Suk-yeol, who took the office in May 2022, scrapped the nuclear phaseout policy by the previous Moon Jae-in administration (2017–2022). In August 2022, the incoming Yoon administration disclosed the first draft of the "Basic Plan for Long-term Electricity Supply and Demand" (BPE) which aims to increase the share of nuclear in power generation at the expense of slowing down the increase of renewables.

South Korea's nuclear fleet, owned by Korea Hydro & Nuclear Power (KHNP), is located at the Hanbit, Hanul, Kori and Wolsong sites. The average number of reactors per site in South Korea is the highest in the world. Kori with seven reactors at the site and 7,489 MW is the world's largest nuclear power plant.

According to the Korean Statistical Information Service (KOSIS), nuclear power provided 158 TWh (gross) in 2021, slightly less than the 160 TWh in 2020, providing 27.5 percent of the electricity, versus 29 percent in 2020.[262] (See Table 7).

South Korea Abandons Nuclear Phaseout Policy

As mentioned in the South Korea Focus in WNISR2021, the future of South Korean energy policy, especially regarding the role of nuclear power generation for the coming years, was likely to be determined by the outcome of the March 2022 presidential election.

The newly elected President, Yoon Suk-yeol, from the conservative People Power Party (PPP) said during the electoral campaign that he would make South Korea the strongest nuclear power country. Even before he became President, Yoon had been very critical of the nuclear phaseout policy implemented by President Moon. In fact, it was one of the reasons why he resigned as Prosecutor General appointed by President Moon and became a politician.

The nuclear power policy has been one of the major issues of political confrontation between the liberal Democratic Party of Korea (DPK) and the conservative People Power Party (PPP) since 2017 when President Moon Jae-in was elected with a pledge to phase out nuclear power.

The establishment of the nuclear phaseout policy in 2017 was supported by the majority of the population. After the Fukushima accident in 2011, a series of events occurred in South Korea pushed political leaders to support the phaseout of nuclear power. Such events include the complete station blackout of the Kori-1 reactor in 2012,[263] a series of nuclear corruption scandals over safety in 2012 and 2013, local referendum victories against new nuclear projects in

262 - KOSIS (KOrean Statistical Information Service), "Power Generation by Energy Source", Updated 22 July 2022, see https://www.index.go.kr/potal/main/EachDtlPageDetail.do?idx_cd=1339, accessed 4 September 2022.

263 - *WNN*, "Safety culture questions after loss of power at Kori 1", 22 March 2012, see https://www.world-nuclear-news.org/RS_Safety_culture_questions_after_loss_of_power_at_Kori_1_2203121.html, accessed 9 September 2022.

Samcheok and Yeongdeok in 2014 and 2015 respectively.[264] The alarming Gyeongju earthquake not far from nuclear power plants in 2016 also raised a serious concern about the safety of nuclear reactors in South Korea.[265] (See previous WNISR editions for additional information on these events.)

Therefore, it was not surprising that four out of the five major candidates —Moon Jae-in, Yoo Seung-min, Ahn Cheol-soo and Sim Sang-jung— in the 2017 presidential election all agreed on no more nuclear power plant construction. However, the positions of the major candidates on nuclear power in the 2022 election changed.

The Justice Party's candidate, Sim, was unchanged, with a clear aim to reach a nuclear phaseout by 2040. The ruling Democratic Party of Korea's candidate, Lee Jae-myung, promised to continue Moon's long-term nuclear phaseout policy. The People's Party's candidate, Ahn Cheol-soo, changed from his nuclear phaseout position in 2017 and promised to discard the policy. Lastly, the People Power Party's candidate, Yoon, pledged to scrap the nuclear phaseout strategy.

President Moon's nuclear phaseout policy consisted of continuing the reactors already under construction but not building new ones and guaranteeing defined lifetimes of existing nuclear reactors. The nuclear reactors (APR1400) under construction in South Korea usually get operational licenses for 60 years from the start.

Therefore, under Moon's policy, even if it was called a nuclear "phaseout" policy, the total installed nuclear capacity was increased in Moon's term and the complete phaseout was scheduled to be seen in 2085 when Shin-Kori 6, currently under construction, is to reach the end of its 60-year lifetime. Compared to other nations, for instance, Germany, which aims to phase out nuclear by 2022, and Taiwan, which plans to phase it out by 2025, the Korean phaseout plan was very slow and more like a "program limitation" policy.

Even if South Korea had continued Moon's phaseout policy, nuclear power would still have played a role towards the goal of carbon neutrality by 2050, because the total nuclear installed capacity then would have been 11,400 megawatts with nine operating reactors.

Moon's nuclear phaseout policy was reflected in several administrative plans, but it was not legislated. Therefore, the policy was easily overturned following the regime change after the 2022 presidential election.

As President Yoon led the investigation on the earlier-than-scheduled closure of Wolsong-1 when he was the head of the Prosecutor's Office, the prosecution under the Yoon administration continues the investigation on Wolsong 1. For instance, on 19 August 2022, the Presidential Archives were raided by prosecutors who investigate possible illegalities in the Moon administration's decision in 2019 to close an aging nuclear reactor ahead of its legal expiration date.

The Yoon administration aims to extend the lifetime of the existing reactors. Under current regulations, KHNP needs to submit a Periodic Safety Review within two to five years prior to

264 - Choe Sang-Hun, "Bitter Debate Over Nuclear Power Simmers in Rural South Korea", *The New York Times*, 5 January 2016.

265 - Jane Chung, "South Korea's biggest earthquake triggers nuclear safety concerns", *Reuters*, 13 September 2016, see https://www.reuters.com/article/us-southkorea-nuclear-quake-idUSKCN11J0R2, accessed 9 September 2022.

the operating license expiration to apply for a lifetime extension. The current administration plans to modify these conditions and increase the application lead time to five to ten years to facilitate lifetime extensions under the current legislative period. If such an amendment is implemented, the number of reactors which the Yoon administration can extend within its term (2022–2027) increases from 10 to 18 reactors, among which six reactors whose lifetime would be extended for a second time.[266]

The Yoon administration also aims to start to build at least two more reactors, Shin-Hanul-3 and -4. These two reactors are expected to be completed in 2032 and 2033 respectively.[267] If the construction was completed prior to the closure of the first reactors, Hanul would become the world's largest and densest nuclear power plant, with a 11,500 MW capacity and ten reactors located at one site. For comparison, the total installed capacity of Europe's largest nuclear power plant, Zaporizhzhia site in Ukraine, is 5,700 MW with six reactors.

It is not clear yet whether the new government will also revive the plan of building six reactors at Samcheok and Yeongdeok which was cancelled by the preceding administration.

A recent public survey shows that President Yoon's overall job approval rating around his 100 days in office was 32.9 percent and when it comes to Yoon's discarding of South Korea's nuclear phaseout policy, 47.5 percent of the respondents favored the option "the nuclear phaseout policy needs to continue", 37.8 percent answered "the nuclear phaseout policy needs to be scrapped", and the remaining 14.7 percent chose "don't know".[268]

The Ministry of Industry, Trade and Energy (MOTIE) under the Yoon administration unveiled the draft of the 10th Basic Plan for Long-term Electricity Supply and Demand (BPE, 2022–2036) in August 2022.[269] The plan increases the share of nuclear in the future electricity mix, aiming for 33 percent by 2030, compared to 24 percent under the plans of the Moon administration. (See Table 8). With the increase of nuclear power in the draft plan, the share of fossil fuels (coal and LNG) barely changes, while the share of new and renewable energy (NRE) decreases significantly, a surprising strategic orientation in these times of climate emergency.

266 - *The Hankyoreh*, "수명연장 원전 10기→18기…윤석열표 '원전강국' 제도 가시화 " ["Lifetime extended reactors 10 → 18... Yoon's 'a strong nuclear country' policy is coming"], 20 April 2022 (in Korean), see https://www.hani.co.kr/arti/society/environment/1039762.html, accessed 5 September 2022; and David Dalton, "New President Aiming To Boost Reactor Lifetime Extensions", *NucNet*, 22 April 2022.

267 - MOTIE, "「제10차 전력수급기본계획」 총괄분과위 실무안 공개" ["Disclosure of the draft of the 10th Basic Plan for Electricity Supply and Demand], 30 August 2022 (in Korean), see http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_seq_n=165956&bbs_cd_n=81&currentPage=1&search_key_n=title_v&cate_n=1&dept_v=&search_val_v=%EA%B8%B0%EB%B3%B8%EA%B3%84%ED%9A%8D, accessed 14 September 2022.

268 - *CBS Nocutnews,* "이준석 사태 속 尹지지 33%…' 부정 전망' 46%는 숙제" ["Yoon's approval rating 33% in the middle of Lee Junseok scandal.. the 46% negative outlook is Yoon's task"], 16 August 2022 (in Korean), see https://www.nocutnews.co.kr/news/5802134, accessed 5 September 2022.

269 - MOTIE, "「제10차 전력수급기본계획」 총괄분과위 실무안 공개" ["Disclosure of the draft of the 10th Basic Plan for Electricity Supply and Demand], 30 Aug 2022 (in Korean), see http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_seq_n=165956&bbs_cd_n=81&currentPage=1&search_key_n=title_v&cate_n=1&dept_v=&search_val_v=%EA%B8%B0%EB%B3%B8%EA%B3%84%ED%9A%8D, accessed 14 September 2022.

In June 2022, President Yoon and his administration already pledged KRW1,000 billion (US$725 million) in investments for the industry by 2025.[270] The current administration also means to allocate KRW400 billion (US$$_{2022}$309 million) for the development of SMRs.[271]

Table 7 – 2021 Electricity Mix in South Korea

	Nuclear	Coal	LNG	NRE	Other	Total
Production (TWh)	158.0	198.0	168.3	43.1	9.4	**576.7**
Share of Electricty	27.4%	34.3%	29.2%	7.5%	1.6%	**100%**

Source: KOSIS (KOrean Statistical Information Service), 2022

Table 8 – Projections of 2030 Electricity Mix in South Korea according to Different Plans

Plan	Production / Share of Electricity	Nuclear	Coal	LNG	NRE(a)	Zero Carbon(b)	Other	Total
9th BPE (2020) Moon Administration	TWh	146.4	175.1	136.6	121.7	-	6.0	585.8
	Share	25.0%	29.9%	23.3%	20.8%	-	1.0%	100%
New NDC (2021) under Moon Admin.	TWh	146.4	133.2	119.5	185.2	22.1	6.0	612.4
	Share	23.9%	21.8%	19.5%	30.2%	3.6	1.0%	100%
10th BPE(c) (2022) Yoon Administration	TWh	201.7	130.3	128.2	132.3	13.9	8.6	615.0
	Share	32.8%	21.2%	20.9%	21.5%	2.3%	1.3%	100%

Sources: MOTIE 2020[272], CNC 2021[273], MOTIE 2022[274]

Notes:

BPE=Basic Plan for Long-term Electricity Supply and Demand; **NDC**=Nationally Determined Contributions (under the Paris Agreement)

(a) - New and Renewable Energy (NRE). New energy in South Korea includes IGCC and fuel cell

(b) - Zero carbon sources include hydrogen and ammonia

(c) - Based on the first draft disclosed on 30 August 2022 by the MOTIE and scheduled to be finalized by the end of 2022.

Even though South Korea has the lowest renewables share in the electricity mix amongst OECD member countries,[275] the Yoon administration intends to still lower the ambitions on renewables and increase the share of nuclear with over 40 percent of electricity still coming from fossil fuels in 2030.

270 - *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.

271 - *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.

272 - MOTIE, "「제9차 전력수급기본계획(2020~2034) 공고" ["Announcement of the 9th Basic Plan for Electricity Supply and Demand"], 28 December 2020 (in Korean), see http://www.motie.go.kr/motie/in/ay/policynotify/announce/bbs/bbsView.do?bbs_seq_n=66387&bbs_cd_n=6, accessed 14 September 2022.

273 - Carbon Neutrality Commission(CNC), "「2030 국가온실가스 감축목표(NDC) 상향안" ["A Strengthened Plan of the 2030 National Greenhouse Gas Reduction Goals (NDC)"], 18 October 2021.

274 - MOTIE, "「제10차 전력수급기본계획」 총괄분과위 실무안 공개" ["Disclosure of the draft of the 10th Basic Plan for Electricity Supply and Demand"], 30 August 2022 (in Korean), see http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_seq_n=165956&bbs_cd_n=81&currentPage=1&search_key_n=title_v&cate_n=1&dept_v=&search_val_v=%EA%B8%B0%EB%B3%B8%EA%B3%84%ED%9A%8D, accessed 14 September 2022.

275 - OECD, "Data—Renewable Energy", as of 2020, see https://data.oecd.org/energy/renewable-energy.htm, accessed 9 September 2022.

At the completion ceremony of the first nuclear reactor in Korea, Kori-1, in 1978, President Park Chung-hee said that since Korea had become one of the nuclear power countries, it was also time to "put more effort into developing new energies such as solar, wind and geothermal". More than 40 years have passed since 1978.

Reactor Construction

All three reactors under construction—Shin-Hanul-2 and Shin-Kori-5 and -6—are APR-1400 design. Construction of Shin-Hanul-2 launched in June 2013 has been nearly completed, but startup dates have been pushed back several times. More recently, Unit 2 was expected to enter commercial operation in May 2022,[276] which did not happen and is now expected in 2023.[277] Ongoing issues at Unit 1 cast further uncertainty on the operation timeline at Unit 2.

The Nuclear Safety and Security Commission (NSSC) conditionally approved issuance of an operating license for Shin-Hanul-1 on 9 July 2021, almost 10 years after the issuance of the construction license in December 2011. It took the NSSC 79 months to come to a decision following KHNP's application in December 2014, a record as the longest licensing procedure in the history of Korean nuclear regulation. The delay of the issuance of operating license for Shin-Hanul-1 was mainly due to safety concerns including passive autocatalytic recombiner (PAR) destined to remove hydrogen from the reactor containment in certain accident scenarios, and possible aircraft risk issues. Therefore, the approval was made with four specific technical conditions attached.[278]

Shin-Hanul-1 reached first criticality on 22 May 2022 and first grid connection on 9 June 2022. However, these were done before KHNP successfully completed the PAR test and submitted their final report to the regulator. In fact, NSSC changed the conditions of the operating license of Shin-Hanul-1 on 11 August 2022. As of early September 2022, it is uncertain whether Shin-Hanul-1 will start commercial operation in 2022 and the outcome of various reviews will also affect the issuance of an operating license for Shin-Hanul-2.

Two other reactors, Shin Kori-5 and -6, have been under construction since April 2017 and September 2018 respectively and were planned to be completed in March 2023 and June 2024 respectively.[279] However, in March 2021, KHNP applied for an extension of the construction license, with a completion schedule for Shin Kori-5 now extended one additional year until 31 March 2024, and for Shin Kori-6, nine months later to 31 March 2025.[280]

276 - *WNN*, "Korean reactor starts supplying electricity", 10 June 2022, see https://www.world-nuclear-news.org/Articles/Korean-reactor-starts-supplying-electricity, accessed 9 September 2022.

277 - WNA, "Nuclear Power in South Korea | Nuclear Energy in the Republic of Korea", June 2022, see https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx, accessed 9 September 2022.

278 - NSSC, "NSSC Commissioners Approved Issuance of Operating License of Shinhanul Unit 1", Press Release, Nuclear Safety and Security Commission, 9 July 2021, see https://www.nssc.go.kr/ajaxfile/FR_SVC/FileDown.do?GBN=X01&BOARD_SEQ=1&SITE_NO=3&BBS_SEQ=46038&FILE_SEQ=1, accessed 9 September 2022

279 - S&P Global, "S Korea's 9 nuclear plants restarting Sep-Oct to pressure LNG demand", 2 September 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/090220-s-koreas-9-nuclear-plants-restarting-sep-oct-to-pressure-lng-demand, accessed 9 June 2021.

280 - KHNP, "Shin-Kori #5,6", Undated, see https://www.khnp.co.kr/eng/url, accessed 9 September 2022.

Permanent Closure

There have been only two reactors, Kori-1 and Wolsong-1, closed in Korea. Ten additional reactors totaling 8,450 MW will reach the end of their operating license before 2030. These reactors are Kori-2 to be closed in 2023, Kori-3 in 2024, Kori-4 and Hanbit-1 in 2025, Hanbit-2 and Wolsong-2 in 2026, Hanul-1 and Wolsong-3 in 2027, Hanul-2 in 2028 and finally Wolsong-4 in 2029. The Yoon administration will likely try to extend the operating license of all of these reactors starting with Kori-2 in 2022. Opposition to the government plans starts organizing, and a local civil society group in Busan where Kori-2 is located organized a press conference on 25 August 2022, claiming a shutdown of Kori-2 at the expiry of its current license.[281] It is possible that the lifetime extensions will not go through as easily as the new administration hopes, considering safety concerns and economic implications, as well as lack of public acceptance.

Radiation Leakage at Wolsong NPP

On 10 January 2021, a Korean media exposed that groundwater near storage tanks of the Wolsong nuclear plant contained levels of tritium exceeding legal limits. According to a report written in 2020 by Korea Hydro & Nuclear Power (KHNP), tritium was discovered in groundwater near the storage tanks for spent fuel rods. The report said that the amounts found in the water in 2020 were as high as 13.2 times the safety standard.[282] In response to public concern on the leakage, NSSC formed a civil investigation team for the scientific assessment of the tritium issue at the Wolsong plant.

Greenpeace East Asia Seoul Office and Ulsan Federation for Environmental Movements (KFEM Ulsan) on 7 March 2022 announced a criminal complaint against KHNP for environmental damage to the site of the Wolsong nuclear power plant and requested a public-interest audit on NSSC, KINS and KHNP, claiming that the long-term leakage of radioactive substances would represent a serious scandal that saw numerous safety management failures cumulate.[283]

On 4 May 2022, the civil investigation team published the "Progress of the second-phase investigation on the tritium at the Wolsong NPP and future plans",[284] a follow-up of the "Progress of the first-phase investigation and future plan" presented on 10 September 2021.[285]

The report contained a staggering admission:

281 - *The Hankyoreh*, "부산 시민단체 "고리2호기 수명 연장 절차 멈춰라"" ["Busan NGOs "Stop Lifetime Extension of Kori-2""], 22 August 2022 (in Korean), see https://www.hani.co.kr/arti/area/yeongnam/1056154.html, accessed 7 September 2022.

282 - Ser Myo-ja"Plant contamination called a gamma ray in a teacup", *Korea JoongAng Daily*, 12 January 2021, see https://koreajoongangdaily.joins.com/2021/01/12/national/politics/Wolsong-tritium-Korea-Hydro-and-Nuclear-Power/20210112185500572.html, accessed 9 September 2022.

283 - *Naeil*, "월성원전 '방사성 물질 누설' 공익감사 청구" ["Request for a Public Audit of the Leakage of Radioactive Substance at Wolsong NPP"], 8 March 2022 (in Korean), see http://www.naeil.com/news_view/?id_art=416245, accessed 7 September 2022.

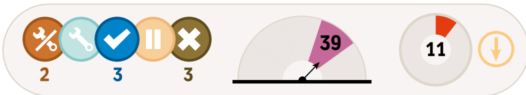
284 - NSSC, "NSSC Shares the Progress of the Second-phase Investigation of Tritium in the Wolsong Site and Future Plans", Press Release, Nuclear Safety and Security Commission, 4 May 2022, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?MENU_ID=90&CONTENTS_NO=1&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=46100, accessed 9 September 2022

285 - NSSC, "Progress of First-phase Investigation on Tritium Found in Wolsong Site and Future Plans Announced", Press Release, Nuclear Safety and Security Commission, 10 September 2021, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?pageNo=1&pagePerCnt=10&MENU_ID=90&CONTENTS_NO=&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=46055&USER_NAME=&TEL_NO=&WRITER_DI=&_csrf=&SEARCH_FLD=&SEARCH=tritium, accessed 9 September 2022.

> In April 2019, tritium of the maximum concentration of 713,000 Bq/L was detected in the stagnant water in the manhole of the turbine gallery of the Wolsong Unit 3, and tritium of 28,200 Bq/L, in the observation well, WS-2, in May 2019.

The indicated tritium contamination values represent 19 and 475 times the limit of 1,500 Bq per liter set by the Japanese authorities prior to the planned discharge of contaminated water generated by the Fukushima disaster (see Fukushima Status Report).

TAIWAN FOCUS



Taiwan has three operating reactors at Kuosheng (Guosheng) and Maanshan, all owned by the Taiwan Power Company (Taipower), the state-owned utility monopoly. The latest reactor to close was the BWR Kuosheng-1 (or Guosheng), on 1 July 2021.[286] Accordingly, in 2021, nuclear generation dropped by 11.6 percent to 26.8 TWh, compared to 30.3 TWh in 2020, contributing 10.8 percent to the country's electricity production in 2021, compared to 12.7 percent the previous year. Nuclear generation reached its maximum share of 41 percent in 1988.

Following 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.[287]

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-1 was the third Taiwanese reactor to be closed under the current government's nuclear phaseout plan and another milestone in the island's energy transition.

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 EU's sustainability taxonomy.[288] Pro-nuclear lobbying 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.[289] 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. Considering the dire state of the Lungmen project, it is indeed unlikely that a favorable outcome would have translated into policy changes or any concrete action ultimately leading to operation of the plant (see The Lungmen Saga.)

286 - Taipower, "核 1號機燃料池滿今提前停機" ["The fuel pool of Nuclear No. 2 Unit 1 was shut down ahead of schedule today"], 1 July 2021 (in Chinese), see https://www.taipower.com.tw/tc/news_info.aspx?id=4741&chk=75ddf691-44f7-406a-922c-ebf676c2fbd8&mid=17, accessed 5 July 2021.

287 - 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.

288 - 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.

289 - 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.

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 will 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.[290] The authority was to be set up about a decade ago,[291] and an organizational act was passed in early 2013 as part of restructuring ministerial affiliations[292], yet, as of July 2022, the AEC was still exercising regulatory oversight in Taiwan.

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 Unit 1 had been permanently shut down, which was six months earlier than planned.[293] The closure of Kuosheng-1 was originally scheduled for 27 December 2021 when its operating license expired. Nuclear fuel was 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 higher-consumption month of June 2021.[294]

The reactor, which is located on the northern coast of Taiwan, approximately 22 km northeast of Taipei City, was a 985 MW BWR/6 unit supplied by General Electric (GE) and was connected to the grid on 21 May 1981. In its last full year of operation in 2020, it generated 7.4 TWh of electricity and about 4 TWh over the six months it operated in 2021.[295]

Local opposition in Taiwan prevented the construction of additional spent fuel dry storage capacity and is one reason for the early closure of Kuosheng-1. Taipower undertook the installation of high-density spent fuel storage racks (HDFSRs) in the early 1990's at Kuosheng and retrofitting work for even higher density in 2005.[296] In April–June 2017, racks initially intended for Lungmen-2 were installed to expand capacity for two 18-months cycles.[297]

290 - 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.

291 - WNA, "Nuclear Power in Taiwan", Updated July 2022, see https://world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx, accessed 1 September 2022.

292 - 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.

293 - Taipower, "核 1號機燃料池滿今提前停機", 1 July 2021, op. cit.

294 - *WNN*, "Early shutdown for Taiwanese reactor", 1 July 2021, see https://www.world-nuclear-news.org/Articles/Early-shutdown-for-Taiwanese-reactor, accessed 7 July 2021.

295 - PRIS, "Kuosheng-1", IAEA, Updated 4 September 2022, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=556, accessed 4 September 2022.

296 - *NEI Magazine*, "Keeping Kuosheng operating", 15 March 2018, see https://www.neimagazine.com/features/featurekeeping-kuosheng-operating-6084804/, accessed 7 July 2021.

297 - *NIW*, "Briefs—Taiwan", *Nuclear Intelligence Weekly*, 14 April 2017; and Dennis Engbarth, "Taiwan: Kuosheng-1 Restarts Facing Suit Over SFP Expansion", *NIW*, 9 June 2017.

Kuosheng-2 is planned for closure on 15 March 2023, and Maanshan's two PWRs 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.[298]

The Lungmen Saga

A referendum was to be held on 28 August 2021 that included an attempt at overturning the current nuclear phaseout policy, by asking voters to approve the construction restart of two ABWRs at the Lungmen Nuclear Power Plant. Due to the COVID-19 pandemic, the vote was postponed to December 2021 and resulted in the rejection of the proposal by a 5.7 percent margin (47.2 percent in favor, 52.8 percent against).[299]

According to the AEC, as of the end of March 2014, Lungmen-1 was 97.7 percent complete,[300] while Lungmen-2 was 91 percent complete. The plant was by then estimated to have cost NT$300 billion (US$$_{2014}$9.9 billion).[301] 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.[302] 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".[303]

Beyond industrial or political will, a plethora of obstacles compromised the realism of such undertaking. 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.[304]

Even if the seismic fault was proven inactive, numerous further technical challenges would still have to be overcome. As Taipower explained in February 2019 that it would not be able to simply replace major components installed nearly 20 years ago, including instrumentation

298 - *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 1 September 2022.

299 - 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.

300 - Planning Department, "Status and Challenges of Nuclear Power in Taiwan", Atomic Energy Commission, April 2014, see http://www.aec.gov.tw/english/whatsnew/files/20140506-5.pdf, accessed 7 July 2021.

301 - *WNN*, "Political discord places Lungmen on hold", 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.

302 - 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.

303 - Dennis Engbarth, "Taiwan: Tsai Pushes to Defeat Lungmen-4 Revival", *Nuclear Intelligence Weekly*, 9 April 2021.

304 - Ibidem.

and control, as well as full-scale renegotiation with the main supplier General Electric (GE).[305] Taipower stated at the time that it could take at least 6–7 years to complete construction if all of these obstacles were to be overcome, that is without accounting for the negotiation process with GE whose original project team no longer exists.[306] In 2021, the AEC Chairman cited a "10 years or more" timeline until grid connection of both units.[307]

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".[308]

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."[309] GE was cleared at the time by blaming the suspension of the project for its shortcomings—an explanation the company maintains to this day. 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.[310] 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

305 - *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.

306 - Dennis Engbarth, "Taiwan: Extending Reactor Operations 'Infeasible'", *Nuclear Intelligence Weekly*, 1 February 2019.

307 - Dennis Engbarth, "Taiwan: Tsai Pushes to Defeat Lungmen-4 Revival", *Nuclear Intelligence Weekly*, 9 April 2021.

308 - 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.

309 - Dennis Engbarth, "Taiwan: Government Probe Unearths Safety Issues With Lungmen", *Energy Intelligence*, 19 November 2021, op. cit.

310 - Ibidem; and *NIW*, "Technology: Investigation Belies GEH Claims About ABWRs", 19 November 2021.

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 "no legal standing" yet "created the mistaken understanding among a part of society that the report meant that the nuclear power plant was safe."[311]

While the opposition labeled the findings "irrelevant" repeating past declarations that Lungmen-1 had been cleared for testing, voters were more affected by the revelations. A 2019-poll illustrated the impact of cost and delays on public opinion by revealing that a majority of the population supported the project at the time, but support fell from 54 percent to just 44 percent, while opposition rose from 33 percent to 42 percent, once individual respondents were presented with estimates that placed costs of resuming construction at NT$50 billion (US$$_{2022}$1.7 billion) over five years.[312] According to some polls, a slight majority of voters were favorable to the project until November 2021.[313]

WNISR took the units off the construction listing in 2014, where they remain as of 1 July 2021. The IAEA kept listing the Lungmen reactors as under construction at least until June 2019,[314] however, as of 2022 they were no longer listed.[315]

Energy and Climate Policy

Historical public opposition to nuclear power in Taiwan dramatically escalated during and in the months following the beginning of the Fukushima Daiichi disaster which has been 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.[316] On 12 January 2017, the Electricity Act Amendment completed and passed its third reading in the legislature, setting in place Taiwan's energy transition, including the nuclear phaseout.[317] 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.

The closure of Kuosheng-1 in July 2021 prior to summer peak electricity demand has led some to question the merits of the government's energy policy;[318] however, a Taipower official stated that the loss of the reactor would not impact power supply margins as the company had

311 - Ibidem.

312 - Dennis Engbarth, "Taiwan: GEH Awarded $158 Million in Lungmen Dispute", *Nuclear Intelligence Weekly*, 8 March 2019.

313 - Woon Wei Jong, "Taiwanese wavering over referendum on Fourth Nuclear Power Plant", *ThinkChina*, see https://www.thinkchina.sg/taiwanese-wavering-over-referendum-fourth-nuclear-power-plant, accessed 4 September 2022.

314 - IAEA-PRIS, "Taiwan, China", as of 10 June 2019, see https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=TW, accessed 11 June 2019.

315 - IAEA-PRIS, "Taiwan, China", 4 September 2022, op. cit.

316 - MOEA, "Taiwan's New Energy Policy", 6 April 2017, Ministry of Economic Affairs, see https://www.moea.gov.tw/Mns/ ietc_e/content/Content. aspx?menu_id=21511, accessed 7 July 2021.

317 - 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, 1 March 2017, see https://eng.wra.gov.tw/7618/7662/7717/30138/, accessed 7 July 2021.

318 - Darrell Proctor, "Taiwan Shuts Another Reactor as Part of Nuclear-Free Goal", *POWER Magazine*, 7 July 2021, see https://www.powermag.com/taiwan-shuts-another-reactor-as-part-of-nuclear-free-goal/, accessed 7 July 2021.

"anticipated the shutdown for several months and Taipower has controlled for this", through the commissioning of a new 500-MW combined cycle gas turbine (CCGT) and 500 MW of new solar PV installations.[319] There were nevertheless reports about blackouts in August 2021 but the exact causes remain unclear.[320]

President Tsai in October 2020 called for Taiwan to become a leading center of green energy in the Asia-Pacific region.[321] 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.[322] 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.[323] In May 2021, this was increased to 15 GW, thus corresponding to the deployment of 1.5 GW *per year* over the decade.[324]

However, in the shorter term, after stagnating in 2020, offshore wind capacity grew by only 109 MW in 2021, reaching 237 MW, and bringing total installed wind capacity to just 1 GW[325] delivering 2.2 TWh (gross) over the year.[326] Three wind farms with a combined capacity of 1 GW are to come online in 2022.[327]

Meanwhile, Solar PV deployment has proven more effective, 1.9 GW were installed in 2021 bringing the total to 7.7 GW (compared to 0.1 GW in 2011),[328] and according to BP, these provided about 7.9 TWh, a 30.4 percent increase from 6.1 TWh in 2020. Current targets for 2025 place solar capacity at 20 GW and combined renewable energy capacity at 25 percent of the power mix.[329] In 2021, non-hydro renewables provided a combined 2.4 percent of primary energy consumption and 4.2 percent of generated electricity, corresponding to 12.1 TWh,

319 - *Nikkei Asia*, "Taiwan nuclear plant closure tests Tsai's energy transition", 5 July 2021, see https://asia.nikkei.com/Business/Energy/Taiwan-nuclear-plant-closure-tests-Tsai-s-energy-transition, accessed 7 July 2021.

320 - NEI Magazine, "Phasing out nuclear power in Taiwan", 18 August 2021.

321 - Energy Taiwan, "Energy Taiwan Establishing the Trifecta of PV Solar, Wind Power and Smart Energy Storage", 16 October 2020, see https://www.energytaiwan.com.tw/en/news/0D605CE74CB29C4E/info.html?lt=data&cr=7&cid=news; 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.

322 - GWEC, "Offshore Wind Technical Potential in Taiwan", Global Wind Energy Council, June 2022, see https://gwec.net/wp-content/uploads/2021/06/Taiwan_Offshore-Wind-Technical-Potential_GWEC-OREAC.pdf, accessed 5 September 2022.

323 - 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.

324 - *Wind Power Monthly*, "Taiwan ups offshore wind goal with plans to auction 15GW", 11 May 2021, see https://www.windpowermonthly.com/article/1715534/taiwan-ups-offshore-wind-goal-plans-auction-15gw, accessed 7 July 2021; and Bernadette Lee, "Taiwan expands offshore wind capacity, work underway on latest 900 MW of projects", IHS Markit, S&P Global, see https://cleanenergynews.ihsmarkit.com/research-analysis/taiwan-expands-offshore-wind-capacity-with-latest-900-mw-of-pr.html, accessed 5 September 2022.

325 - IRENA, "Renewable Capacity Statistics 2022", 2022, p.31, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 5 September 2022.

326 - BP, "bp Statistical Review of World Energy 2022—71st Edition", June 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 5 September 2022.

327 - Max Tingyao Lin, "Taiwan prepares regulations to meet 2050 net-zero goal despite COP26 exclusion", IHS Markit, S&P Global, 8 November 2021, see https://cleanenergynews.ihsmarkit.com/research-analysis/taiwan-prepares-netzero-rules-for-2050-goal-despite-cop26-excl.html, accessed 5 September 2022.

328 - IRENA, "Renewable Capacity Statistics 2022", 2022, op. cit.

329 - Max Tingyao Lin, "Taiwan prepares regulations to meet 2050 net-zero goal despite COP26 exclusion", IHS Markit, S&P Global, 8 November 2021, see https://cleanenergynews.ihsmarkit.com/research-analysis/taiwan-prepares-netzero-rules-for-2050-goal-despite-cop26-excl.html, accessed 6 September 2022.

compared to 10.4 TWh in 2020 and 3.4 TWh in 2012. Taiwan was ranked thirtieth in the Renewable Energy Country Attractiveness Index 2021.[330]

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.[331]

As of 2021, the island remains heavily dependent on energy imports—with over 97 percent of imported primary energy that year[332]—and is the ninth biggest fossil fuel consumer per capita in the world, according to S&P Global calculations. In 2021, coal still dominated electricity generation with a 44 percent contribution, followed by a 37 percent share from natural gas.[333] The government's strategy—summarized by MOEA as "Promote Green Energy, Increase Nature Gas, Reduce Coal-fired, Achieve Nuclear-free"—would see natural gas consumption increase substantially, and provide 50 percent of gross electricity production by 2025.[334] Such reliance on gas requires a very stable supply, which in the light of unfolding geopolitical changes is a high risk strategy.

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$30.2 billion) budget to 2030, of which NT$210.7 billion (~US$7.1 billion) are allocated to "renewables and hydrogen", and a further NT$207.8 billion (~US$7 billion) are to be invested in "grid and energy storage". The plan provides for 40 GW of combined wind and solar capacity by 2030, and by 2050, renewables are to represent 60–70 percent of the country's energy mix, representing an installed capacity of 40–80 GW in solar and 40–55 GW of offshore wind alone[335].

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[336].

330 - EY, "Renewable Energy Country Attractiveness Index", October 2021, see https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/power-and-utilities/ey-recai-58th-edition-top-40-ranking-october-2021.pdf, accessed 4 September 2022.

331 - 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, 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.

332 - Bureau of Energy, "Energy Supply and Demand Situation in Taiwan, R.O.C.", Ministry of Economic Affairs, 2022, see https://www.moeaboe.gov.tw/ECW/main/content/wHandMenuFile.ashx?file_id=1390, accessed 4 September 2022.

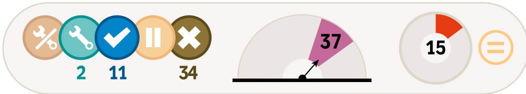
333 - Max Tingyao Lin, "Taiwan's net-zero roadmap promises $170 billion in spending, renewable expansion; more could be required", IHS Markit, S&P Global, 8 April 2022, see https://cleanenergynews.ihsmarkit.com/research-analysis/taiwans-netzero-roadmap-promises-170-billion-in-spending-renew.html, accessed 5 September 2022.

334 - MOEA, "Promote Green Energy, Increase Nature Gas, Reduce Coal-fired, Achieve Nuclear-free", Undated, see https://www.moea.gov.tw/MNS/english/Policy/Policy.aspx?menu_id=32904&policy_id=19, accessed 5 September 2022.

335 - NDC, "Taiwan's Pathway to Net-Zero Emissions in 2050", Presentation, National Development Council, Government of Taiwan, 30 March 2022; 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, see https://cleanenergynews.ihsmarkit.com/research-analysis/taiwans-netzero-roadmap-promises-170-billion-in-spending-renew.html, accessed 5 September 2022

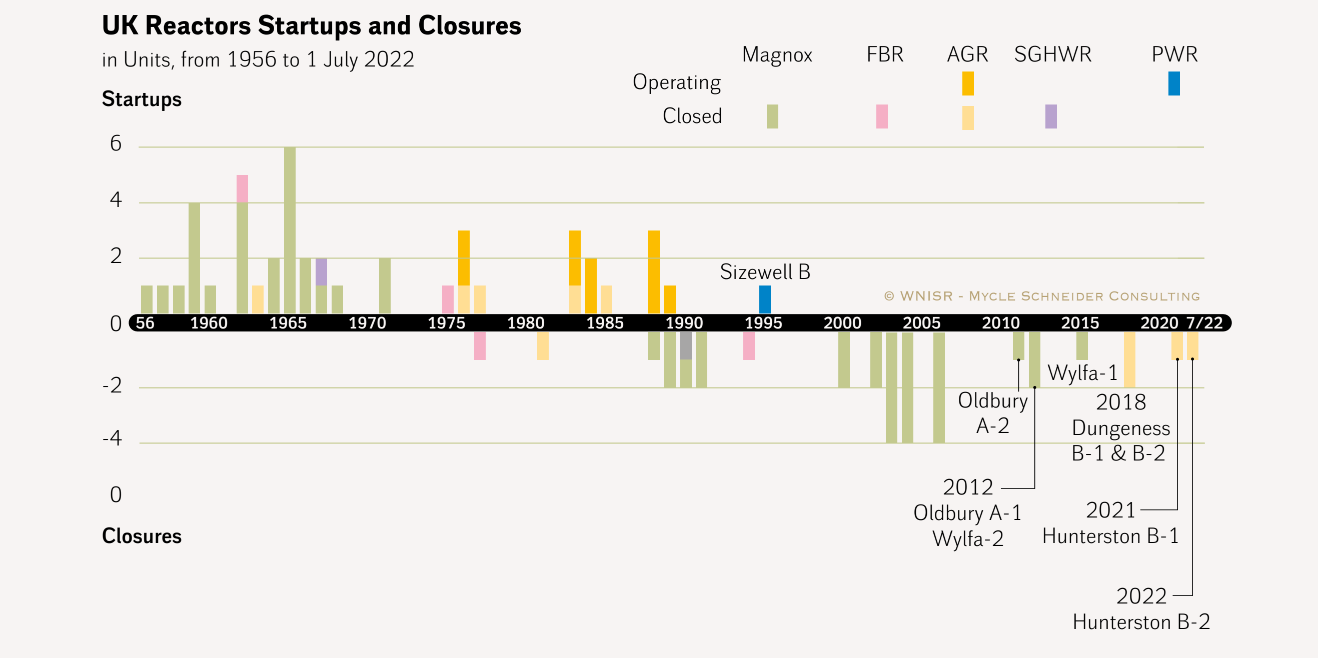
336 -Chung-Han Yang and Chengkai Wang, "The Energy Regulation and Markets Review: Taiwan", *The Law Reviews*, 16 June 2021, see https://thelawreviews.co.uk/title/the-energy-regulation-and-markets-review/taiwan#footnote-055, accessed 7 July 2021.

UNITED KINGDOM FOCUS



As of mid-2022, the United Kingdom operated 11 reactors, following the closure of the two reactors at Hunterston in November 2021 and January 2022, and two units at Dungeness closed in June 2021. In total, 34 nuclear reactors have been closed in the U.K., the second largest number of any country behind the U.S. This includes all 26 Magnox reactors, two fast breeders, one small unit at Sellafield and five Advanced Gas Reactors (AGRs).

Figure 37 · U.K. Reactor Startups and Closures



Source: WNISR with IAEA-PRIS and EDF Energy, 2022

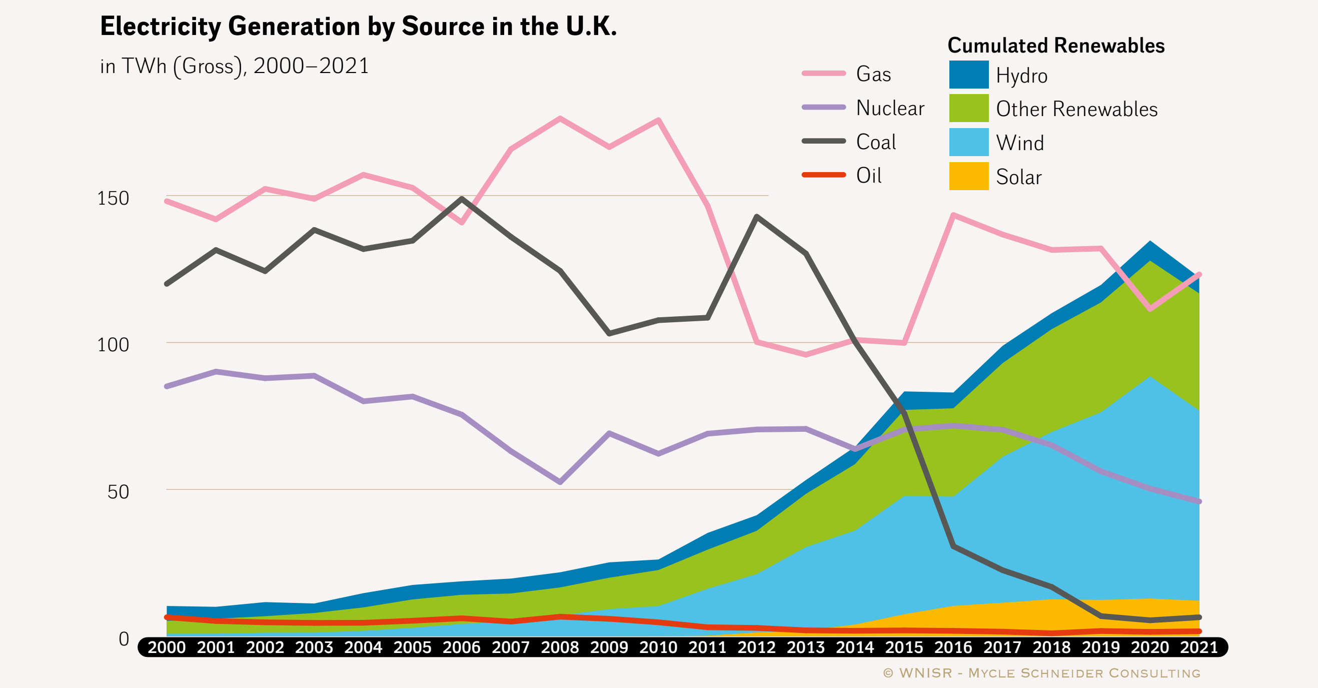
Type of Reactors:

AGR: Advanced Gas Reactors; FBR: Fast Breeder Reactor; PWR: Pressurized Water Reactor; SGHWR: Steam Generating Heavy Water Reactor

In 2021, nuclear plants generated 42 TWh, on the decline for the sixth year in a row, representing 14.8 percent of electricity, down from a maximum share of 26.9 percent in 1997.

The electricity mix in the U.K. has changed rapidly over the past decades as can be seen in Figure 38. The most significant trend has been the rapid increase in the use of renewable energy—from 2.5 percent at the turn of the century to 39.6 percent in 2021—the rapid demise in the use of coal—from 39.2 percent in 2012 to 2.1 percent one decade later—and the relatively more gradual decline in the generation of electricity from nuclear power. The closure of all the Magnox reactors and now the often-extended outages and closure of some of the AGRs has resulted in nuclear generation decreasing from 64 TWh in 2017 to 42 TWh in 2021.

Figure 38 · Electricity Generation by Source in the U.K. 2000–2021



Source: U.K. Government, DUKES 2022[337]

While Great Britain—including England, Scotland, and Wales, but not Northern Ireland—has left the EU Internal Energy Market as a consequence of Brexit, electricity trade continues with EU member states. In fact, electricity trade is increasing as new interconectors become operational. In 2021, a new connection was made with Norway, the North Sea Link, a 1.4 GW ~720 km cable[338], which follows on the back of new interconnectors to France in 2020 and to Belgium in 2019. In total, there are now seven cables with a total capacity of 7.4 GW,[339] and while these allow power to flow both ways, the British market is increasingly a net importer: 24 TWh in 2021 compared to 19 TWh in 2018,[340] although this may change in 2022, due to the low production in France (see France Focus).

EDF Energy, a wholly owned subsidiary of French state-controlled utility EDF, is the majority owner of the company Lake Acquisitions that owns the operating nuclear reactors. Centrica has a minority share (20 percent) in Lake Acquisitions. Centrica reported an adjusted operating *loss* in nuclear operations of £38 million (US$$_{2021}$51.3 million) in 2021, up from £17 million (US$$_{2020}$23 million) in 2020, and compared to a *profit* of £19 million (US$$_{2019}$25 million) in 2019,

337 - BEIS, "National Digest of UK Energy Statistics – Electricity fuel use, generation and supply", Department for Business, Energy & Industrial Strategy, U.K. Government, 2022, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1094460/DUKES_5.6.xlsx, accessed 28 July 2022.

338 - National Grid Group, "National Grid powers up world's longest subsea interconnector between the UK and Norway", Press Release, 1 October 2021, see https://www.nationalgrid.com/national-grid-powers-worlds-longest-subsea-interconnector-between-uk-and-norway, accessed 19 July 2022.

339 - National Grid, "Interconnectors", June 2022, see https://www.nationalgrid.com/national-grid-ventures/interconnectors-connecting-cleaner-future, accessed 19 July 2022.

340 - BEIS, "Energy Trends", National Statistics, Department for Business, Energy & Industrial Strategy, U.K. Government, 30 June 2022, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1086789/Energy_Trends_June_2022.pdf, accessed 19 July 2022.

as unplanned outages resulted in having to buy power from the market to fulfill hedge[341], electricity sold in advance.[342] Given the higher power prices in 2022, EDF Energy may make significant profits this year, although the early closure of a number of reactors may dampen these.

Closure of the Advanced Gas-cooled Reactors (AGRs)

For several years EDF has tried to coax additional operation out of its aging AGR fleet through extensive maintenance and backfitting during extended outages.

Managing reactors as they age—the U.K. fleet age exceeds 37 years now (see Figure 39) 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 Hunterston B reactors in 2016. This can lead to the degradation of the keying system, a vital component which houses the fuel, the control rods, and the coolant (CO_2). Their cracking or distortion could impact the insertion of the control rods or the flow of the coolant. There are also issues of erosion of the graphite, and a number 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.[343]

"The situation had dramatically changed with EDF officially closing Dungeness B-1 and -2 in June 2021, Hunterston B in January 2022."

Beside the small unit at Windscale, 14 AGRs were built (see Figure 37) operating at seven stations and despite increasing concerns all reactors were said to be in service at the start of 2021 although Hunterston B and Hinkley Point B had generated little electricity in the previous two years, and Dungeness B none since 2018. 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 had dramatically changed with EDF officially closing Dungeness B-1 and -2 in June 2021, Hunterston B in January 2022, and with Hinkley Point B scheduled for closure in July 2022. Furthermore, Hartlepool and Heysham A are due to close in 2024 and even the closure of the last two units (Torness and Heysham B), previously due in 2030, was brought forward to 2028.[344] (See Table 9)

341 - Companies take out a hedge—which is a form of insurance—that guarantees availability at a fixed price.

342 - Centrica, "Centrica plc Annual Report and Accounts 2021—Strategic Report", April 2022, see https://www.centrica.com/media/5513/centrica-ar21-strategic-report.pdf, accessed June 2022; and Centrica, "Annual Report and Accounts 2019", 17 March 2020, p. 32, see https://www.centrica.com/media/4204/annual-report-and-accounts-2019.pdf, accessed 5 July 2022.

343 - ONR, "Operating power stations: Graphite core of AGRs", Office for Nuclear Regulation, 5 March 2021, see http://www.onr.org.uk/civil-nuclear-reactors/graphite-core-ageing.htm, accessed 11 April 2021.

344 - 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; 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 *WNN*, "EDF Energy confirms Hinkley Point B shutdown plan", 1 June 2022, see https://www.world-nuclear-news.org/Articles/EDF-Energy-confirms-Hinkley-Point-B-shutdown-plan; both accessed 5 July 2022.

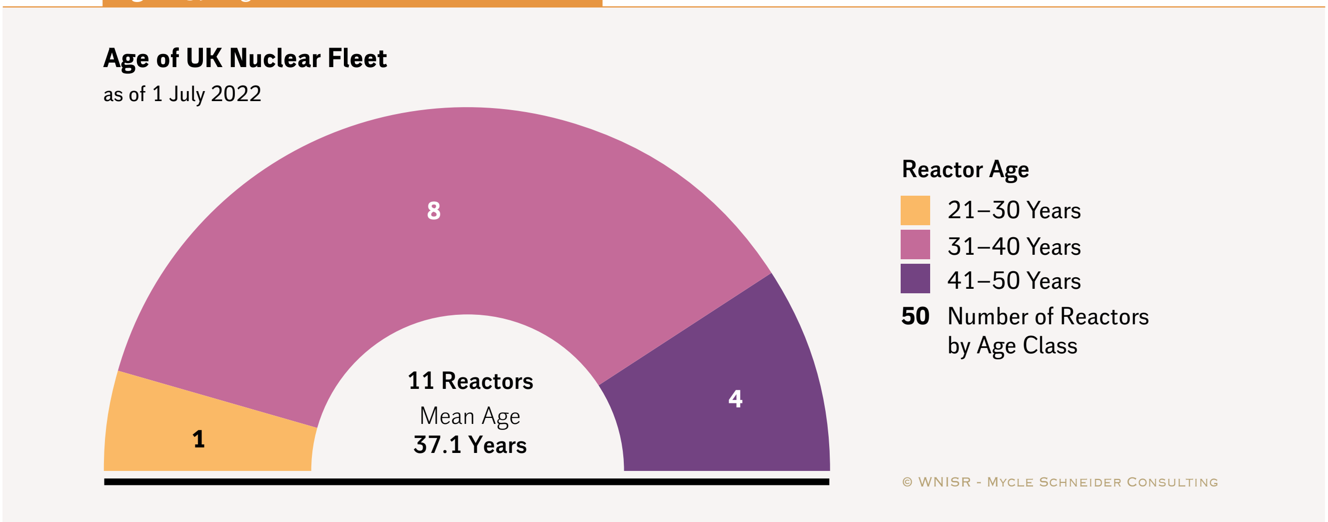
Table 9 – Status of U.K. EDF AGR Nuclear Reactor Fleet (as of 1 July 2022)

Reactor	Net Capacity (MW)	Grid Connection	Closure/ Expected Closure
Dungeness B-1 **Dungeness B-2**	545 545	03/04/1983 29/12/1985	Closed Last power in 2018
Hartlepool A-1 **Hartlepool A-2**	590 595	01/08/1983 31/10/1984	March 2024
Heysham A-1 **Heysham A-2**	485 575	09/07/1983 11/10/1984	March 2024
Heysham B-1 **Heysham B-2**	620 620	12/07/1988 11/11/1988	March 2028 March 2028
Hinkley Point B-1 **Hinkley Point B-2**	485 480	30/10/1976 05/02/1976	July 2022
Hunterston B-1 **Hunterston B-2**	490 495	06/02/1976 31/03/1977	Closed 2021 Closed January 2022
Torness-1 **Torness-2**	595 605	25/05/1988 03/02/1989	March 2028 March 2028

Sources: EDF Energy, 2022

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$$_{2021}$32.7 billion] in March 2021, and there remains a significant risk that the costs could rise further". Furthermore, despite having already provided £10.7 billion [US$$_{2022}$13 billion] (from a total value of the funds of £14.8 billion [US$$_{2021}$20.3 billion]), the Government was committed to "top up the Fund with taxpayers' money, providing an injection of capital of £5.1 billion [US$$_{2020}$6.9] in 2020–21 with a further £5.6 billion [US$$_{2022}$7 billion] expected in 2021–22".[345]

Figure 39 · Age Distribution of U.K. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2022

345 - Committee of Public Accounts, "The Future of the Advanced Gas-cooled Reactors", Third Report of Session 2022–23, House of Commons, 20 May 2022, see https://publications.parliament.uk/pa/cm5803/cmselect/cmpubacc/118/report.html, accessed 5 July 2022.

Pathways to Net Zero

The U.K. has set one of the most ambitious greenhouse gas emissions targets in the world, committing to a 68 percent reduction from 1990 levels by 2030 and 78 percent by 2035[346] compared to a 50 percent reduction achieved in 2020.[347] The U.K. Government has also committed to a zero-emission power sector by 2035.[348]

"Renewables are cheaper than alternative forms of power generation in the UK and can be deployed at scale to meet increased electricity demand in 2050."

In June 2019, the Parliament set in law a commitment to reach net zero carbon emissions by 2050 and as part of this process six select committees jointly agreed to establish a citizens' assembly on climate change and how the Net Zero Target could be met. Special attention was to be given to the findings of the citizens' assembly as "it is unique: a body whose composition mirrors that of the U.K. population."[349]

The citizens' assembly found

- three main disadvantages to nuclear: "its cost, safety, and issues around waste storage and decommissioning".
- Support for nuclear power was second lowest to the use of fossil fuels with Carbon Capture and Storage (CCS), with 34 percent of the assembly agreeing or strongly agreeing that it should be part of how the U.K. generates electricity, compared to 78 percent for onshore wind, 95 percent for offshore wind and 81 percent for solar.[350]

The Climate Change Committee, an independent body established to advise the Government on meeting its climate commitments has produced a report in 2019 on how the U.K. can meet its Net Zero commitments. Three out of five of the Committee's energy 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. The Committee concluded:[351]

> Renewables are cheaper than alternative forms of power generation in the UK 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. (…)

346 - U.K. Government, "UK enshrines new target in law to slash emissions by 78% by 2035", Press Release, 20 April 2021, see https://www.gov.uk/government/news/uk-enshrines-new-target-in-law-to-slash-emissions-by-78-by-2035, accessed 19 July 2022.

347 - BEIS and National Statistics, "2020 UK Greenhouse Gas Emissions, Final Figures", Department for Business, Energy & Industrial Strategy, U.K. Government, 1 February 2022, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1051408/2020-final-greenhouse-gas-emissions-statistical-release.pdf, accessed 5 July 2022.

348 - BEIS, "Plans unveiled to decarbonise UK power system by 2035", Department for Business, Energy & Industrial Strategy, U.K. Government, Press Release, 7 October 2021, see https://www.gov.uk/government/news/plans-unveiled-to-decarbonise-uk-power-system-by-2035, accessed 6 July 2022.

349 - Climate Assembly UK, "The Path to Net Zero", House of Commons, 2020, see https://www.climateassembly.uk/report/read/final-report-exec-summary.pdf, accessed 6 July 2022.

350 - Ibidem. Note: the U.K. public opinion survey echoes a 2020 study on France where nuclear—also with 34 percent—came in second lowest to oil with solar getting 91 percent and wind (general) 82 percent of "good or very good" opinions, see IRSN, "Baromètre IRSN 2020 sur la perception des risques et de la sécurité", 23 June 2020 (in French), see https://www.irsn.fr/fr/actualites_presse/communiques_et_dossiers_de_presse/pages/20200623_barometre-risques-securite-france-2020.aspx, accessed 17 June 2022.

351 - Committee on Climate Change, "Net Zero – Technical Report", 2 May 2019, see https://www.theccc.org.uk/publication/net-zero-technical-report/, accessed 12 April 2021.

> 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 is clearly recognizing the economic and deployment advantages of renewables 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".[352] This put forward milestones for the sector, including:

- 2021: Launch of Phase 2 of U.K. SMR design development;
- Mid 2020s: Hinkley Point C (HPC) 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. In this they stated that their aim was to "bring at least one largescale nuclear project to the point of Final Investment Decision by the end of this Parliament [2024], subject to clear value for money and all relevant approvals".[353] In an accompanying press statement the Government said it would begin negotiations with EDF on Sizewell C.[354] However, the approval has a requirement for a "value-for-money" hurdle to be passed, which given the current economics of nuclear vs. renewables is likely to be difficult. Then U.K. minister for Investment Lord Gerry Grimstone told the *Financial Times* at the time "If you read the energy white paper before Christmas it's by no means certain that this country is going to be building large nuclear power stations".[355]

The U.K. has failed in the area of energy efficiency, which is all the more surprising as it is the one measure that can rapidly and cheaply address energy security, climate change, and affordability simultaneously. Domestic buildings are the largest user of natural gas and account for 20 percent of greenhouse gas emissions, however, inadequate progress has been made on energy efficiency.

In January 2021, the U.K. Government proposed that all new homes be "zero carbon ready" by 2025, meaning they should emit 75–80 percent less carbon than those built to the current standards introduced in 2013. But this is just the latest target for new buildings, and when part of the EU, the U.K. Government signed up, through the Energy Performance of Buildings Directive, required all new buildings to be "Nearly Zero Energy" by 31 December 2020,[356] and

352 - BEIS, "The Ten Point Plan for a Green Industrial Revolution", Department for Business, Energy & Industrial Strategy, U.K. Government, November 2020, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf, accessed 6 July 2022.

353 - BEIS, "Energy White Paper – Powering our Net Zero Future", 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 11 April 2021.

354 - BEIS, "Government sets out plans for clean energy system and green jobs boom to build back greener", Department for Business, Energy & Industrial Strategy, Press Release, 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 14 December 2020.

355 - Daniel Thomas and Jim Pickard, "UK woos sovereign wealth funds over green investments", *Financial Times*, 28 April 2021, see https://www.ft.com/content/f2352470-2bef-4b15-bae8-fb9e002212d0, accessed 5 May 2021.

356 - Glen Dimplex, "The Energy Performance of Buildings Directive and the NZEB 2020 target for new buildings", 25 August 2020, see https://www.gdhv.co.uk/energy-performance-buildings-directive-and-nzeb-2020-target-new-buildings, accessed 22 May 2022.

before that in 2006 the Government announced that by 2016 all new homes would be "net energy buildings".[357] In 2007, energy analyst Walt Patterson published an article for Chatham House which highlighted the importance of energy efficiency, specially for foreign policy, which stated:

> Forget fighting wars to protect oil and gas supplies, worry less about unsavoury leaders who extract a price for access to these precious products. Instead, order some loft insulation for homes, offices and especially government buildings.[358]

If this advice had been followed, the U.K. would likely today be in a very different place, one with affordable household heating and far greater energy independence. That is true, of course, not only for the U.K.

Security of Supply

As with many other countries, especially those in Europe, the invasion of Ukraine by Russia in February 2022 and the subsequent spike in energy prices led the Government to announce that it would review its energy policy and particularly around energy security. However, the U.K. is in a markedly different position to the Member States of the EU, in that it is not highly dependent on Russia for its fuel, that, in 2021, supplied just 4 percent of the natural gas consumed, 9 percent of its oil, and 27 percent of its coal.[359] This is a result of domestic production, although this is decreasing, and in the case of gas of the far greater use gas from Norway and the Netherlands and of Liquified Natural Gas (LNG), as well as increasing renewable energy deployment.

In April 2022, the Government published its revised strategy[360] which was met with howls of derision from many interested parties.[361] As well as the failure to prioritize demand side measures, given the policy's stated purpose to increase supply diversity away from dependency on Russian fuels, it is remarkable that the policy has chosen to ignore measures that can be introduced most rapidly. The document does not set any further target for onshore wind and goes further saying that it "will not introduce wholesale changes to current planning regulations for onshore wind", the very regime that slowed its deployment. Then on solar, while it looks more promising on the surface, as it says "we expect a five-fold increase [in capacity] by 2035", there is little indication of how such an increase would be achieved. The ruling party, the Conservatives, given their support mainly in rural areas, are particularly sensitive to local planning concerns and have therefore used the policy to shore up their chances of re-election.

357 - Matt Weaver, "Brown pledges to build 'zero carbon' homes", *The Guardian*, 6 December 2006, see https://www.theguardian.com/environment/2006/dec/06/politics.greenpolitics, accessed 22 May 2022.

358 - Walt Patterson, "Energy, Fuel and Efficiency: Loft Insulation as Foreign Policy", Chatham House, 1 July 2007, see https://www.chathamhouse.org/publications/the-world-today/2007-07/energy-fuel-and-efficiency-loft-insulation-foreign-policy, accessed 22 May 2022.

359 - Paul Bolton, "Imports of energy from Russia", Research Briefing, House of Commons Library, U.K. Parliament, 14 June 2022, see https://commonslibrary.parliament.uk/research-briefings/cbp-9523/, accessed 7 July 2022.

360 - U.K. Government, "British Energy Security Strategy", April 2022, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1069973/british-energy-security-strategy-print-ready.pdf, accessed 7 July 2022.

361 - Will Stevens, "'Wholly inadequate': Government's Energy Security Strategy 'fails to rise to the challenge facing the country'", REA, The Association for Renewable Energy & Clean Technology, 7 April 2022, see https://www.r-e-a.net/wholly-inadequate-governments-energy-security-strategy-fails-to-rise-to-the-challenge-facing-the-country/, accessed 19 July 2022.

Offshore wind does get more direct encouragement by setting a specific target of 50 GW by 2030—including 5 GW of new floating wind—up from 14 GW. The Government proposes to support this by reducing the planning and development time by 50 percent. However, the Government chose to highlight its 'big bet' on nuclear power as the cornerstone of the new policy, with then Prime Minister, Boris Johnson saying "we're embracing the safe, clean, affordable new generation of nuclear reactors, taking the UK back to pre-eminence in a field where we once led the world".[362]

Furthermore, the Government said in April 2022 that "A new government body, Great British Nuclear, will be set up immediately to bring forward new projects, backed by substantial funding," and it would "launch the £120 million [US$$_{2021}$161.5 million] Future Nuclear Enabling Fund this month".[363] The nuclear fund had previously been announced in the spending review of October 2021[364] and was ultimately launched in May 2022.[365] To the great deception of the industry, there was no new commitment of government funding. "I was expecting this to be bad, but not as bad as it was", one industry source told *Nuclear Intelligence Weekly*.[366]

The main details of the "new" plan[367] were:

- 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), which has already been announced.
- Two further projects, including SMRs, in the next Parliament (scheduled for between January 2025–2029).

Four nuclear projects in total by 2030:

- Initiate the selection process in 2023 for further U.K. projects, with the intention that Government will enter negotiations with the most credible projects 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 of 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.

362 - Ibidem.

363 - BEIS and Prime Minister's Office, "Major acceleration of homegrown power in Britain's plan for greater energy independence", U.K. Government, Press Release, 6 April 2022, see https://www.gov.uk/government/news/major-acceleration-of-homegrown-power-in-britains-plan-for-greater-energy-independence, accessed 22 May 2022.

364 - U.K. Government, "Autumn Budget and Spending Review 2021—A stronger economy for the British people", 27 October 2021, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1043688/Budget_AB2021_Print.pdf, accessed 7 July 2022.

365 - *NEI Magazine*, "UK launches Future Nuclear Enabling Fund", *Nuclear Engineering International*, 16 May 2022, see https://www.neimagazine.com/news/newsuk-launches-future-nuclear-enabling-fund-9701659, accessed 22 May 2022.

366 - Stephanie Cooke and Phil Chaffee, "Latest", *Nuclear Intelligence Weekly*, 8 April 2022.

367 - U.K. Government, "British Energy Security Strategy", April 2022, op. cit.

Nuclear Newbuild

As noted, 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 use the EPR design. Formally the development of a new reactor at Bradwell, continues, based on the Hualong One design, although geopolitical concerns are likely to slow or cancel the project due to engagement of Chinese partners.

More definitive action was taken by the Government in 2022, and in its spending review of 2021, it was announced that £1.7 billion (US$$_{2021}$2.29 billion) were being made available "to enable a final investment decision for a large-scale nuclear project in this Parliament" and that "the government remains in active negotiations with EDF over the Sizewell C project." In addition, the Government was making available £385 million (US$$_{2021}$518 million) towards advanced nuclear R&D; and £120 million (US$$_{2021}$161.5 million) for a new Future Nuclear Enabling Fund to address barriers to entry.[368]

Hinkley Point C

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[369] announced updates to the October 2013 provisional agreement of commercial terms of the deal for the £16 billion (US$19.5 billion) overnight cost of construction of Hinkley Point C (HPC).[370] The estimated cost of construction has since risen at the following times:

- In 2017, it stood at £$_{2015}$19.6 billion (US$$_{2015}$25.3 billion), up from the £$_{2015}$18.1 billion (US$$_{2015}$23.2 billion)— EDF said at the time that the £1.5 billion (US$1.9 billion) increase results 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."[371]
- In November 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 (in 2015 values) now being estimated between £21.5 billion (US$26.6 billion) and £22.5 billion (US$27.9 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$0.9 billion) over and above these estimates, so the upper end of the range was £23.2 billion (US$28.8 billion).372 EDF stated that "management of the project remains mobilised to begin generating power from Unit 1 at the end of

368 - U.K. Government, "Autumn Budget and Spending Review 2021—A stronger economy for the British people", 27 October 2021, op. cit.

369 - Department of Energy & Climate Change, "Hinkley Point C to power six million UK homes", U.K. Government, Press Release, 21 October 2015, see https://www.gov.uk/government/news/hinkley-point-c-to-power-six-million-uk-homes, accessed 11 April 2021.

370 - BEIS and Prime Minister's Office, "Initial agreement reached on new nuclear power station at Hinkley", Press Release, 21 October 2013, see https://www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley.

371 - 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 11 April 2021.

372 - 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 11 April 2021.

2025", which does not appear to be a clear statement of confidence in the then current schedule.373

- 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$$_{2015}$32.6–34.1 billion), a rise of £0.5 billion (US$0.7 billion).[374]
- Less than three months later, in May 2022, EDF then announced that cost estimates had further risen by £$_{2015}$3 billion (US$$_{2015}$4.4 billion), to between £$_{2015}$25–26 billion (US$$_{2015}$37–38.5 billion) and that its startup would be delayed by an additional year to June 2027.[375]

The critical points of the HPC deal were a Contract for Difference (CfD), effectively a guaranteed real electricity price for 35 years, which, depending on the number of units ultimately built, would be £$_{2012}$89.50–92.50/MWh (US$$_{2022}$133.7–139.8/MWh), with annual increases linked to the Retail Price Index.[376] In early 2020, EDF broke down the £92.50/MWh (US$$_{2022}$133.7/MWh) strike price saying that £19.5 (US$$_{2022}$23.7) would go toward operating and maintenance costs, and only £11 (US$$_{2022}$13.4) to standard construction costs, excluding financing. The remaining £62 (US$$_{2022}$75.4) covers risk, with £26 (US$$_{2022}$31.6) for financing costs for typical regulated asset without construction risk and £36 (US$$_{2022}$43.8) to cover first-of-a-kind construction risk.[377]

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$26.9 billion), but the loan guarantees were never taken up.[378] EDF announced in October 2015 its intention to sell non-core assets worth up to €10 billion (US$11.4 billion) over five years to help finance HPC and other capital-intensive projects.[379]

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 has impacted upon the amount EDF has to pay. Since 2013, the cost of EDF's expected share of the project has gone up by about 150 percent[380] and significantly

373 - Ibidem.

374 - EDF Energy, "Annual Report and Financial Statements", March 2022, see https://www.edfenergy.com/sites/default/files/edf_energy_holdings_limited_fy21_signed_financial_statements_full.pdf, accessed 8 July 2022.

375 - EDF, "Hinkley Point C Update", Press Release, 19 May 2022, see https://www.edf.fr/sites/groupe/files/epresspack/3081/ccb6205433272bb0cbfac560cea3b537.pdf, accessed 19 May 2022.

376 - EDF, "Agreement reached on commercial terms for the planned Hinkley Point C nuclear power station", Press Release, 21 October 2013, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/investors-analysts/events/special-announcements/agreement_reached_on_commercial_terms_for_the_planned_hinkley_point_c_nuclear_power_station.pdf, accessed 13 July 2022.

377 - Phil Chaffee, "United Kingdom: Industry Pushes for Government Action", *Nuclear Intelligence Weekly*, 6 March 2020.

378 - Phil Chaffee, "United Kingdom: Difficulties With Hinkley's IUK Support", *Nuclear Intelligence Weekly*, 4 December 2015.

379 - 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 21 May 2020.

380 - Steve Thomas, "Financing the Hinkley Point C", PSIRU, University of Greenwich, Commissioned by the Theberton & Eastbridge Action Group on Sizewell, January 2020, see https://www.nuclearconsult.com/wp/wp-content/uploads/2020/01/HPC-finance-Steve-Thomas.pdf, accessed 11 April 2021.

contributed to its large debt load.[381] The HPC cost overruns were part of credit-rating agency Standard & Poor's (S&P) rationale to downgrade EDF's rating in June 2020[382] and, after a further downgrade in February 2022[383], the placement on credit-watch negative in May 2022[384]. In the same rating actions, S&P downgraded EDF's U.K. subsidiary EDF Energy to BB, deep in speculative territory ("junk") and put it as well on credit-watch negative for potential further downgrade. These developments will further increase the cost of EDF's debt service.

The administration of Prime Minister Theresa May 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.[385] 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".[386] Reportedly, U.S. diplomats have been "celebrating the UK's effort to push a Chinese company out of a sensitive nuclear power project" in the fall of 2021.[387] The comment refers to the Bradwell project where CGN was planning to build its own design (see hereunder).

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),[388] after over two years of consultation, review and adoption process. There are at least 3 key differences between RAB and Contract for Difference (CfD) models. One is consumers paying finance costs, another is that the owners would be institutional investors such as pension funds, sovereign wealth funds etc and the third is 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 project developer could charge consumers upfront for the construction, which would be broken down into different phases during the build process.

381 - EDF, "EDF Annual Results 2021", 18 February 2022, see https://www.edf.fr/sites/groupe/files/2022-02/fy-results-2021-english-transcript.pdf, accessed 13 July 2022.

382 - S&P Global Ratings, "Research Update: French Utility EDF Downgraded To 'BBB+' On Prolonged Operational Weakness, Lower Output Due To COVID-19; Outlook Stable", 22 June 2020, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/investors-analysts/credits/rating/sp-edf-ratings-direct-edf-downgraded-to-bbb2020-06-22.pdf, accessed 12 July 2022.

383 - S&P Global Ratings, "Research Update: Electricite de France Downgraded To 'BBB' From 'BBB+' On Strong Debt Increase In 2022-2023; Outlook Negative", 21 February 2022, see https://www.edf.fr/sites/groupe/files/2022-02/sp-edf-ratings-direct-2022-02-21.pdf, accessed 17 July 2022.

384 - S&P Global Ratings, "Research Update: Electricite de France Placed On CreditWatch Negative On Further Nuclear Issues And Increase In Debt", 24 May 2022, see https://www.edf.fr/sites/groupe/files/2022-05/sp-press-release-2022-05-24_0.pdf, accessed 17 July 2022.

385 - 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 11 April 2021.

386 - 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 21 May 2020.

387 - *The Independent*, "US celebrates 'win' as Britain looks to push China out of nuclear energy sites", 29 September 2021.

388 - U.K. Parliament, "Nuclear Energy (Financing) Act 2022 (c.15)", 31 March 2022, see https://bills.parliament.uk/bills/3057, accessed 22 May 2022.

Furthermore, consumers would pay the finance charges so borrowing would be effectively interest free to the owners in the construction phase.

In 2019, EDF claimed that all households would have to pay only about £6 (US$7.5) per year additionally for them to build the proposed reactors at Sizewell C.[389] In May 2022, the BEIS Secretary of State, Kwasi Kwarteng told householders to prepare for a "small rise" in their energy bills.[390]

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 the construction cost is

> 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.[391]

It is further noted that at the FID for Hinkley Point C it was estimated to have a construction cost (excluding financing cost) of £$_{2021}$6,400/kW (US$$_{2021}$8,646.4), but the governments model is assuming construction costs of £$_{2021}$7,700–13,000/kW (US$$_{2021}$10,363–17,496/kW).[392]

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 key for nuclear projects as financing represents a significant share of the overall project costs. Furthermore, by breaking the construction into different phases, it is expected that this would 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 the 9.2 percent on HPC to around 5.5–6 percent.[393] However, as a 2019-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.[394]

Furthermore, the consumer protection association, Citizens Advice stated in their response to the consultation that:

> While there are credible reasons to believe that a RAB model would reduce the cost of capital associated with bringing forward new nuclear power stations, these are outweighed by

389 - David Sheppard, "EDF forecasts nuclear plant project would add £6 a year to UK bills", *Financial Times*, 11 June 2019, see https://www.ft.com/content/897d548a-8c34-11e9-a24d-b42f641eca37, accessed 23 May 2020.

390 - Hannah Baker, "Hinkley Point could save households £1bn on energy bills, says EDF", *Business Live*, 16 May 2022, see https://www.business-live.co.uk/economic-development/hinkley-point-c-nuclear-plant-23951914, accessed 22 May 2022

391 - BEIS, "Regulated Asset Base Model for new nuclear - Impact Assessment", Department for Business, Energy and Industrial Strategy, 26 October 2021, see https://publications.parliament.uk/pa/bills/cbill/58-02/0174/ImpactAssessment.pdf, accessed 22 May 2022.

392 - Ibidem.

393 - 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 23 May 2020.

394 - 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 12 July 2022.

> the risk of highly material increases in the volume of capital that consumers will need to finance.[395]

A key selling point for the Government was a hope that funding would not have to come from the Treasury—and therefore remains 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 as a U.K. Government balance sheet debt, given the support it is given.[396]

Other U.K. New-Build Projects

Sizewell C

EDF and CGN are also preparing to launch the development of a follow-on to HPC, the Sizewell C project. Chinese investment would be limited to 20 percent, leaving EDF with 80 percent. The budget—about £500 million (US$$_{2022}$607)—to get to FID is nearly spent and CGN is not obliged to pay more and the signals from the EDF Reference Document are that it is either unwilling or won't be allowed to spend more. The 80/20 split covers only the stage up to final investment decision. There is no agreement to invest beyond that stage.[397] Given the apparent problems EDF is having financing HPC, this makes the Sizewell project even more difficult. Despite this, a public engagement process has been ongoing, and EDF was expected to submit a planning application, a so called "development consent order" in February 2020, but concerns by statuary agencies about the readiness of the application followed by the pandemic and the Government's control measures led it being delayed until May 2020.[398] On 24 June 2020, the Planning Inspectorate, accepted the application and consequently the next stage of the planning process could begin.[399] However, in October 2020, EDF announced it intended to make changes to the application, leading to further delay.[400] The final decision on whether to grant a development consent order to build Sizewell-C was given by the Government in July 2022[401].

395 - Citizens Advice, "Response to BEIS consultation on whether it should move to a Regulated Asset Base (RAB) model to finance new nuclear power stations", Press Release, 11 October 2019, see https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Energy%20Consultation%20responses/Response%20to%20BEIS%20consultation%20on%20adopting%20a%20RAB%20model%20for%20new%20nuclear%20projects%20(corrected).pdf, accessed 12 July 2022.

396 - Phil Chaffee, "United Kingdom: Policy Void Prompts Developer Scramble", *NIW*, 30 October 2020.

397 - 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.

398 - EDF Energy, "Sizewell C submits planning application", Press Release, 27 May 2020, see https://www.edfenergy.com/media-centre/news-releases/sizewell-c-dco, accessed 11 April 2021.

399 - 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", National Infrastructure Planning, Secretary of State for the Ministry of Housing, Communities and Local Government, Email to Richard Bull, EDF Energy, 2020, see https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010012/EN010012-002268-A05%20Notification%20of%20decision%20to%20accept%20application_.pdf, accessed 26 June 2020.

400 - 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 4 May 2021.

401 - Planning Inspectorate, "The Sizewell C Project development consent decision announced", Press Release, GOV.UK, 20 July 2022, see https://www.gov.uk/government/news/the-sizewell-c-project-development-consent-decision-announced, accessed 20 July 2022.

"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."

EDF is hoping that it can sequence the construction of Sizewell C with the completion of HPC, so that workers can move from one project to another. But given the earliest conceivable preliminary construction works start date of Sizewell C in 2024, this seems impossible. EDF is optimistic that it can reduce construction costs, with their estimate in 2020 put at £18 billion (US$$_{2020}$22 billion).[402] 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$44.5/MWh),[403] as a result of EDF's "base case" for Sizewell C's cost being £20 billion (US$24.8 billion), with 60 percent financed by loans.[404] In its planning documents, EDF confirmed construction costs of £20 billion (US$24.8 billion), despite previously suggesting that costs would be 20 percent lower than HPC thus limited to £18 billion (US$22.3 billion).[405]

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 U.K. government in the as-yet un-validated regulatory and financing scheme will make it possible to find third party investors during 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 a 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.[406]

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 May 2024. The Government has also pledged £100 million [US$135 million] for EDF to "help bring [the project] to maturity,

402 - *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 11 April 2021.

403 - Phil Chaffee, "United Kingdom: Industry Pushes for Government Action", *Nuclear Intelligence Weekly*, 6 March 2020.

404 - Roger Murray, "Hinkley Point Cost Overrun- Bad News for Sizewell C?", *Nuclear Intelligence Weekly*, 27 September 2019.

405 - 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 26 June 2020.

406 - 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 4 May 2021.

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".[407]

In June 2022, the U.K. Government bought an option to take a 20 percent share in Sizewell C, should the project reach a final investment decision, in the apparent intention to ease the ousting of Chinese investors.[408]

In the same week 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) which is likely to affect the timing and potentially the scope of the FID, which is currently expected in 2023.

Bradwell

EDF is allowing CGN to use the Bradwell site it had bought as back-up, if either the Hinkley **Point** or Sizewell sites proved not to be viable. CGN plans to build with its own technology, the Hualong One (or HPR-1000) at this site, with EDF taking a 33.5 percent stake,[409] 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,[410] and by February 2020 the ONR had completed Step 3 of the GDA.[411] The final step and the issuing of a Design Acceptance Confirmation (DAC) from Office for Nuclear Regulation (ONR) and a Statement of Design Acceptability (SoDA) from the Environment Agency was made on 7 February 2022.[412] In December 2020, the U.K.'s gas and electricity markets regulator, Ofgem, granted an electricity generating license to the Bradwell Power Generation Company Ltd.[413]

In August 2019, the United States blacklisted CGN for allegedly stealing the country's 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.[414] This and the increasing breakdown in the relationship between China, the U.S. and to some extent Europe, may well impact on the development of Bradwell as will the current economic climate and

407 - BEIS, "Government readies Sizewell C nuclear project for future investment", Department for Business, Energy and Industrial Strategy, UK Government, Press Release, 27 January 2022, see https://www.gov.uk/government/news/government-readies-sizewell-c-nuclear-project-for-future-investment, accessed 22 May 2022.

408 - 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 17 June 2022.

409 - 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 11 April 2021.

410 - ONR, "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 11 April 2021.

411 - ONR, "Generic Design Assessment (GDA) of new reactors - Timeline", 5 March 2021, see http://www.onr.org.uk/new-reactors/timeline.htm, accessed 11 April 2021.

412 - CGN and EDF, "UK HPR1000 - GDA Process", 7 February 2022, see https://www.ukhpr1000.co.uk/, accessed 22 May 2022.

413 - *NEI Magazine*, "UK's Bradwell B granted electricity generating licence", 21 December 2020, see https://www.neimagazine.com/news/newsuks-bradwell-b-granted-electricity-generating-licence-8420726/, accessed 12 April 2021.

414 - 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 5 July 2021.

the likelihood of a global recession. In particular for the U.K., there is ongoing and growing concern over the situation in Hong Kong. Consequently, it has been suggested that as nuclear power plants "are part of the U.K.'s strategic national infrastructure, and China is no longer a friend to be trusted with such levers of power" it is impossible to envisage the Government approving the Bradwell station.[415] Furthermore, there is increased attention on the Bradwell project with the cancellation of negotiations about future nuclear projects in the Czech Republic and Romania in 2020 due to security concerns with China.[416]

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.. This would ban them from engagement in either Sizewell C or Bradwell. The Chinese Government responded by saying that "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."[417]

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, as well as Wylfa Newydd on Anglesey and Oldbury on Severn in South Gloucestershire, owned by Hitachi-GE. However, as of mid-2022, work had been suspended on all of 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 for the next generation of nuclear technology, with up to £215 million (US$$_{2020}$278 million) going to Rolls-Royce's SMR program.[418] Rolls-Royce is in the final stages of completing its feasibility study and is hoping that its technology will complete the Generic Design Assessment (GDA) process with U.K. regulators around September 2024 and deliver first power in about 2030.[419] As noted in the SMR Chapter, in November 2021, Rolls Royce announced that it had received £210 million (US$281 million) in government funding and £195 million (US$261 million) in private funds and then an additional £85 million (US$112 million) from the Qatar Investment Authority.

The reactor is said to be able to be used for power, hydrogen production and for the manufacturing of jet fuel, and its multipurpose will enable a larger number of reactors to be

415 - 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 12 April 2021.

416 - America Hernandez, "Czech nuclear tender competition dodges Russian and Chinese bids", *Politico*, 24 June 2021, see https://www.politico.eu/article/czech-nuclear-tender-competition-dodges-russian-and-chinese-bids/, accessed 12 July 2022.

417 - *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 22 May 2022.

418 - BEIS and Prime Minister's Office, "The Ten Point Plan for a Green Industrial Revolution", Department for Business, Energy & Industrial Strategy, HM Government, November 2020, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf; and BEIS, "Advanced Nuclear Technologies", Department for Business, Energy & Industrial Strategy, 7 March 2022, see https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies#the-low-cost-nuclear-challenge; both accessed 13 July 2022.

419 - *WNN*, "Rolls-Royce on track for 2030 delivery of UK SMR", *World Nuclear News*, 11 February 2022, see https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR, accessed 22 May 2022.

installed.[420] Rolls-Royce are confident about the price of the units and suggest that the nth-of-a-kind reactor (after five have been built) will be in the order of £1.8 billion (US$2.2 billion) (capex) for 470 MW units and £40–60/MWh (US$48-73/MWh) over 60 years.[421] 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 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."[422]

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 was any confidence that the SMRs would be delivered at the cost quoted that 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 next decade. Furthermore, given the Government's commitment to have a zero-carbon power sector by 2035, before significant new nuclear capacity can come on-line, the likelihood of additional nuclear, beyond Hinkley Point C and possibly Sizewell C in the late 2030s and beyond seems remote, despite the rhetoric of the new Government led by Liz Truss.

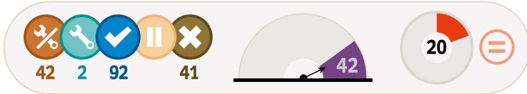
While the political support for nuclear power seems high, especially in light of heightened concerns over energy security, this cannot overcome the material and economic state of the sector. During the past year, the implications of the aging problems at the AGRs have become clearer, with reactors closed and others to cease operation shortly, while the taxpayer is having to pay billions more for ever increasing decommissioning costs. Furthermore, in 2022 the estimated costs of the completion of Hinkley Point C, have risen by at least a further £$_{2015}$3 billion (US$$_{2015}$4.45 billion) to around £$_{2015}$26 billion (US$$_{2015}$38.5 billion) and startup put back at least a year to 2026 or later for the first reactor. The power purchase price for the reactors was set in 2013 at £92.5/MWh (US$$_{2022}$133.7/MWh) when EDF claimed the construction cost would be £$_{2012}$14 billion (US$$_{2022}$17 billion). The cost estimate has nearly doubled since then but the nuclear feed-in tariff did not increase, so it is difficult to see how Hinkley Point C could be anything but a major loss-maker for EDF.

420 - Rolls-Royce, "Small Modular Reactors", Rolls-Royce.com, Undated, see https://www.rolls-royce.com/innovation/small-modular-reactors.aspx#/, accessed 13 July 2022.

421 - *WNN*, "Rolls-Royce on track for 2030 delivery of UK SMR", 11 February 2022, op. cit.

422 - Science and Technology Committee, "Nuclear research and technology: Breaking the cycle of indecision", HL Paper 160, 3rd Report of Session 2016–17, House of Lords, 2 May 2017, see https://publications.parliament.uk/pa/ld201617/ldselect/ldsctech/160/16002.htm, accessed 17 July 2022.

UNITED STATES FOCUS



Overview

With 92 commercial reactors operating as of 1 July 2022, the U.S. continues to possess by far the largest nuclear fleet in the world. One reactor was closed in the year since WNISR2021. Palisades-1 in the state of Michigan was closed on 20 May 2022, after 50 years of operation.[423] The retirement was announced in 2018 to coincide with the expiration of a lucrative power purchase contract between Energy Nuclear and the original owner of Palisades-1, utility corporation Consumers Energy. On 1 September 2022, California enacted legislation to finance a 5-year extension of the Diablo Canyon-1 and -2 reactors, to 2029 and 2030 (see the section Securing Subsidies to Prevent Closures).[424]

"Projected construction costs continued to increase over the last 12 months, and start-up dates were again pushed back. As of June 2022, Vogtle's cost had increased to at least US$30.34 billion."

The U.S. reactor fleet provided 778.2 TWh in 2021[425], a drop of 1.5 percent over 2020. According to IAEA-PRIS, nuclear plants provided 19.6 percent of the nation's electricity in 2021—18.9 percent according to the U.S. Department of Energy's (DOE) Energy Information Administration (EIA)—down from 19.7 percent in 2020 and approaching 4 percentage points below the highest nuclear share of 22.5 percent, reached in 1995. Counting non-commercial rooftop solar PV generation (which increased 18 percent year-over-year), nuclear energy's share of total electricity generation was 18.7 percent in 2021.[426]

With only one new reactor started up in 26 years, the U.S. fleet continues to age, and with a mid-2022 average of 41.6 years, it is amongst the oldest in the world: 47 units have operated for 41 and more years (of which six for more than 51 years) and all but three for 31 and more years (see Figure 40).

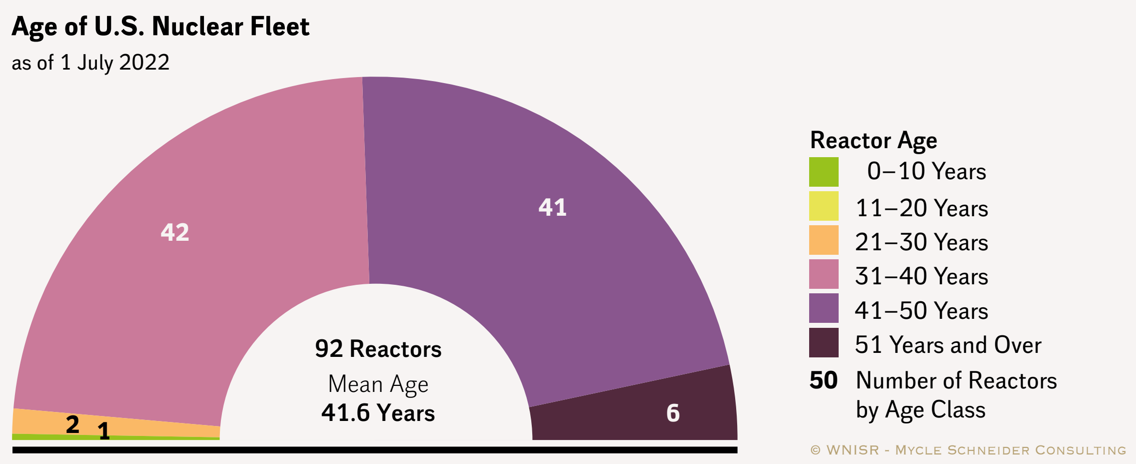
423 - Carolyn Muyskens, "The Palisades nuclear plant is offline. What happens next and is it closed for good?", *Holland Sentinel*, 27 May 2022, see https://www.hollandsentinel.com/story/news/local/2022/05/27/palisades-nuclear-power-plant-prepares-decommissioning/9923747002/, accessed 29 August 2022.

424 - 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.

425 - U.S. Energy Information Administration, "Electric Power Monthly", Table 1.1., U.S. Department of Energy, 24 August 2022, see https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_1_01, accessed 1 September 2022.

426 - Ibidem.

Figure 40 · Age Distribution of the U.S. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2022

Construction continued on the one new nuclear plant in the U.S., the twin AP-1000s at Plant Vogtle Units 3 and 4, in the state of Georgia. Projected construction costs continued to increase over the last 12 months, and start-up dates were again pushed back. As of June 2022, Vogtle's cost had increased to at least US$30.34 billion,[427] according to *Associated Press* calculations.[428] That figure does not include US$3.68 billion in costs that Westinghouse refunded to the co-owners in 2017,[429] putting the total cost of the project over US$34 billion—2.4 times the US$14 billion projected cost at the start of construction in 2013. The most recent cost increases and construction delays are due largely to quality assurance problems in the installation of electrical cabling throughout the plant,[430] as well as administrative errors in failing to complete over 26,000 inspection records.[431] On 3 August 2022, the U.S. Nuclear Regulatory Commission (NRC) authorized the loading of fuel in Unit 3, with a planned startup date in the first quarter of 2023. Georgia Power estimates the startup of Unit 4 before the end of 2023.

Large New Subsidies for Nuclear Power

Since the publication of WNISR2021, the U.S. Congress has enacted two major pieces of infrastructure and energy finance legislation: the Infrastructure Investment and Jobs Act

427 - *Associated Press*, "Georgia nuclear plant's cost now forecast to top $30 billion", as published by *Georgia Public Broadcasting*, 9 May 2022, see https://www.gpb.org/news/2022/05/09/georgia-nuclear-plants-cost-now-forecast-top-30-billion, accessed 7 September 2022.

428 - Jeff Amy, "Co-owners sue Georgia Power in $685M Vogtle contract dispute", *Associated Press*, 21 June 2022, see https://apnews.com/article/politics-lawsuits-florida-georgia-a0eaf5c77e77e2b6ba95f0ad93137572, accessed 1 September 2022.

429 - Georgia Power, "Toshiba fulfills $3.68 billion parent guarantee obligation for Vogtle nuclear expansion," 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.

430 - Jeff Amy, "Nuclear regulators uphold violations at Georgia reactors", *Associated Press*, 19 November 2021, see https://www.statesboroherald.com/local/nuclear-regulators-uphold-violations-georgia-reactors/, accessed 1 September 2022

431 - 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.

(IIJA),[432] with US$1.2 trillion in proposed spending[433]; and the Inflation Reduction Act (IRA),[434] with US$437 billion available.[435] Each law includes significant new spending to promote nuclear energy—existing reactors, new reactors, and enrichment infrastructure. IIJA creates a US$6 billion Civil Nuclear Credits program to support uneconomic reactors at imminent risk of closure, as well as US$3.2 billion to support new reactor demonstration projects. IRA includes five measures that provide subsidies and financing for existing and new reactors:

- Production tax credits for existing reactors;[436]
- Clean energy production and investment tax credits for new energy sources, including new reactors;
- US$40 billion in loan guarantees for new clean energy projects, including new reactors;
- US$250 billion in loan guarantees for existing energy infrastructure (Energy Infrastructure Reinvestment Financing), for which existing reactors are likely to be eligible; and
- US$700 million for High-Assay Low-Enriched Uranium (HALEU).

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 (JTC) latest estimate of the bill's budget impacts projects the production tax credits for existing reactors to cost US$30 billion over the nine years of the program (from 2024 through 2032).[437]

The Energy Policy Act of 2005 (EPACT 2005) was the previous law authorizing large amounts of federal funding for commercial nuclear energy,[438] which directed DOE to provide loan guarantees for new reactors,[439] 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 JTC provided no breakdown by energy source/technology of the

432 - 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.

433 - 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.

434 - House Budget Committee, "H.R. 5376—Inflation Reduction Act of 2022", Public Law No. 117-169, U.S. Congress, enacted 16 August 2022, see https://www.congress.gov/bill/117th-congress/house-bill/5376, accessed 3 September 2022.

435 - 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.

436 - 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.

437 - Joint Tax Committee, "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, 9 August 2022, see https://www.jct.gov/CMSPages/GetFile.aspx?guid=40b08e39-706e-46aa-aef2-438a26936398, accessed 3 September 2022.

438 - 109th Congress, "Energy Policy Act of 2005", Public Law 109–58 enacted 8 August 2005, U.S. Congress, see https://www.congress.gov/109/plaws/publ58/PLAW-109publ58.pdf, accessed 7 September 2022.

439 - EPACT 2005 did not appropriate funds for the loan guarantee program, but subsequent appropriations bills in 2007 and 2009 authorized DOE to provide up to $18.5 billion in loan guarantees for new reactors and up to $4 billion for fuel cycle facilities.

See U.S. DOE, "History: Loan Programs Office," see https://www.energy.gov/lpo/innovative-clean-energy-nuclear-loan-guarantees; and U.S. Government Publishing Office, "Omnibus Appropriations Act, 2009, P.L. No. 111-8, Division C, Title III," see http://www.gpo.gov/fdsys/pkg/PLAW-111publ8/html/PLAW-111publ8.htm; both accessed 4 September 2022.

other tax credits and loan guarantees for which commercial reactors are eligible, but the Nuclear Production Credits alone likely match or exceed the value of all EPACT 2005 spending on commercial reactors.

"There's a deepening understanding within the [Biden] administration that it needs nuclear to meet its zero-emission goals"

As one insider noted 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."[440] With no prospects of major nuclear plant construction in the coming years,[441] 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). However, the 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.

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. Three utility holding companies that controlled approximately one-third of operating reactors a decade ago have divested their nuclear power plants. Entergy has closed or sold off its six merchant reactors since 2014.[442] With the closure and sale of Palisades-1 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. In 2020, FirstEnergy sold off its four nuclear reactors[443] and two coal power plants to Energy Harbor through the bankruptcy settlement of its merchant generation subsidiary, FirstEnergy Solutions.[444]

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 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

440 - 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.

441 - 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.

442 - 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.

443 - Beaver Valley-1 and -2 in Pennsylvania, and Davis-Besse and Perry in Ohio.

444 - 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.

acquiring more merchant reactors "from other companies looking to exit the competitive power business."[445] In 2020, Public Service Enterprise Group (PSEG) announced that it would divest its generation assets except its nuclear holdings,[446] which include interests in four reactors it co-owns with Constellation, as well as the Hope Creek reactor in New Jersey. Following enactment of the IRA, analysts have already speculated that PSEG may strike a deal to transfer its ownership of the reactors to Constellation and fully exit the merchant generation business.[447] 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[448] 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.[449]

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.

During the past few years, utilities have both succeeded and failed in their ongoing efforts to secure state financial support for operating nuclear plants, with the balance being in the industry's favor. As of July 2022, 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[450] 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).

Extended Reactor Licenses

As of 1 July 2022, 84 of the 92 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) did not issue any additional

445 - 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.

446 - 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.

447 - 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.

448 - U.S. NRC, "Issued Early Site Permit - PSEG Site," 8 January 2021, see https://www.nrc.gov/reactors/new-reactors/esp/pseg.html, accessed 4 September 2022.

449 - 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.

450 - 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.

20-year license renewals. Four reactors are currently listed as intending to apply for license extension in the period 2022–2024.[451] 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.

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."[452] As of 4 May 2021, the NRC had granted Subsequent Renewed Operating Licenses to six reactors,[453] which would permit operation from 60 to 80 years. Applications for a further nine reactors are under review.[454]

However, in February 2022, the NRC issued an unprecedented order effectively suspending the approvals it had granted for four reactors,[455] 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) in approving them on the basis of an inapplicable Generic Environmental Impact Statement (GEIS). Initially, 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.[456] However, two of the NRC Commissioners dissented from the decision, arguing this interpretation violates the NRC's obligations under the NEPA.[457] As a result of the expiration of two Commissioners' terms in 2021, the dissenting commissioners then held the majority of two to one, and determined to avoid legal challenges in the courts and suspend the previous approvals.

451 - U.S.NRC, "Future Submittals of Applications", as of 12 January 2022, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 6 September 2022.

452 - Office of Nuclear Reactor Regulation, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report", U.S. NRC, Final Report, NUREG-2191, Vol. 2, July 2017, see https://www.nrc.gov/docs/ML1718/ML17187A204.pdf, accessed 10 June 2020.

453 - Turkey Point-3 and -4 (2020), Peach Bottom-2 and -3 (2020), and Surry-1 and -2 (2021). See U.S. NRC, "Status of Subsequent License Renewal Applications", 9 June 2022, see https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html, accessed 1 September 2022.

454 - North Anna-1 and -2; Oconee-1, -2, and -3; Point Beach-1 and -2; St. Lucie-1 and -2.

455 - 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, "Memorandum and Order CLI-22-02", 24 February 2022, see https://www.nrc.gov/docs/ML2205/ML22055A496.pdf; and U.S. NRC, "Memorandum and Order CLI-22-04", 24 February 2022, see https://www.nrc.gov/docs/ML2205/ML22055A557.pdf; both accessed 1 September 2022.

456 - 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, 12 November 2020, see https://www.nrc.gov/docs/ML2031/ML20317A110.pdf, accessed 11 August 2021.

457 - Paul M. Bessette, Ryan K. Lighty and Scott D. Clausen, "NRC Reaffirms Its Decision Allowing SLR Applicants to Rely on License Renewal GEIS", *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.

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[458] (updated in 2013[459]), covering a broad array of environmental impacts that the NRC deemed common to all initial license renewals. 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 doing so, the NRC issued a regulation authorizing licensees to use the GEIS for initial license renewals to operate for up to 60 years. At the Commissioners' direction, the NRC is in the process of updating the GEIS to cover operation from 60 to 80 years. It must also amend its regulations to authorize the use of the updated GEIS in subsequent license renewal applications.[460]

While not guaranteeing reactors' continued operation, multiple applications are expected over the coming years for subsequent license renewals. Duke Energy Corporation has said it plans to seek license extensions for all 11 of its reactors.[461] The federal legislation providing extended financial support for reactor operations are likely to encourage additional applications for 80-year operational licenses.

Reactor Closures

The retirement of Palisades-1 in May 2022 marks the completion of Entergy's planned exit from the merchant generation business, preceded by the retirements of Vermont Yankee-1 (2014), Pilgrim-1 (2018), Indian Point-2 (2020), and Indian Point-3 (2021), as well as the 2016 divestiture of FitzPatrick-1 to Exelon. The final shutdown of Palisades-1 was preceded by a proposal initiated by Michigan Governor Gretchen Witmer to apply a federal subsidy under the Civil Nuclear Credit program created by federal infrastructure legislation enacted in December 2021 toward attracting a new owner who would extend the Palisades-1. The proposal failed to garner interest, particularly as Entergy had already entered into a contract to transfer ownership of Palisades-1 and its decommissioning trust fund (DTF) to Holtec International. Entergy has transferred all of its retired reactors to consortia specializing in decommissioning: Holtec and Northstar.

The average age of the six reactors closed in the U.S. over the four-year period 2018–2021 (none was closed in 2017) was 46.5 years (see Figure 41), which remains far below their licensed lifetimes of 60 years.

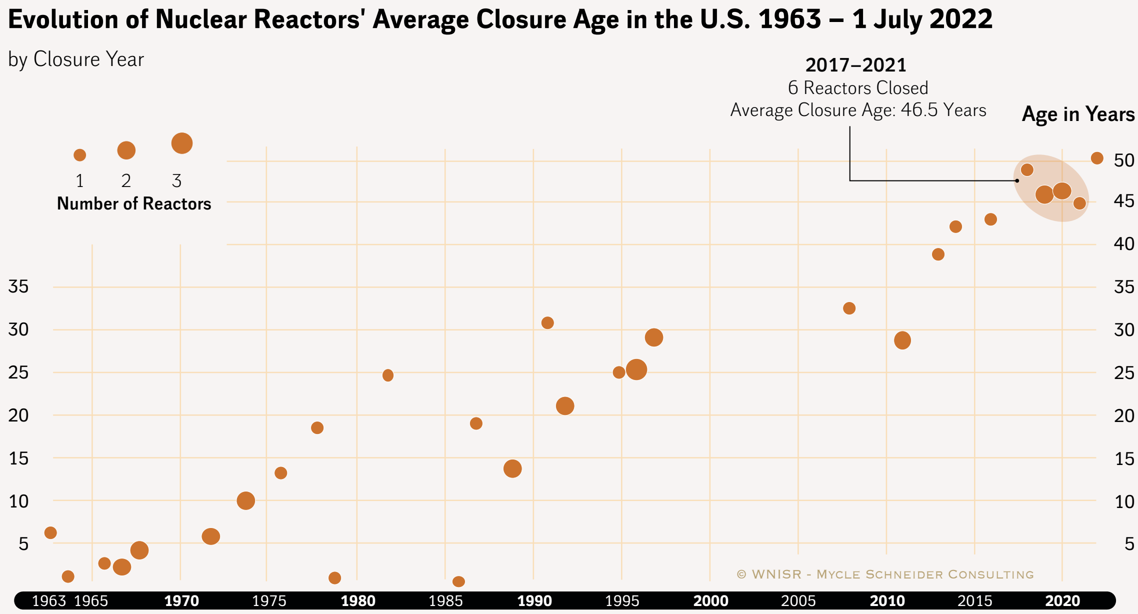
458 - U.S. NRC, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants: Appendices – Final Report (NUREG-1437, Volume 2)", May 1996, see https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/v2/index.html, accessed 1 September 2022.

459 - U.S. NRC, "Reactor License Renewal Process", 10 November 2020, see https://www.nrc.gov/reactors/operating/licensing/renewal/process.html#generic, accessed 1 September 2022.

460 - U.S. NRC, "Memorandum and Order—CLI-22-03", 24 February 2022, see https://www.nrc.gov/docs/ML2205/ML22055A533.pdf, accessed 1 September 2022.

461 - 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.

Figure 41 · Evolution of Average Reactor Closure Age in the U.S.



Sources: WNISR with IAEA-PRIS, 2022

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 (see WNISR2018 Annex 4). A total of 23 reactors were scheduled for early retirement between 2009 and 2025, of which 13 have already been closed, eight had their closure delayed following subsidy programs, and two at Diablo Canyon remain in question (see Figure 42).

The enactment of two major pieces of legislation making federal financing and subsidies available to currently operating nuclear power reactors has disrupted projections for the pace of retirements. The Infrastructure Investment and Jobs Act (November 2021) authorized the issuance of Civil Nuclear Credits to unprofitable reactors, to be administered by the Department of Energy (DOE) through a five-year, US$6 billion federal grant program.[462] Implementation of the program prompted the governors of California and Michigan to request that DOE apply the grants toward preempting the planned retirements of Palisades-1 and Diablo Canyon-1 and -2. Entergy Nuclear, the owner of Palisades-1, did not embrace Governor Witmer's proposal and retired the reactor as planned.

Governor Gavin Newsom's proposal for Diablo Canyon took a different course. Driven by California's seasonal electricity reliability challenges,[463] Newsom's proposal garnered political support and convinced Diablo Canyon's owner, Pacific Gas & Electric (PG&E), to consider breaking an innovative multi-stakeholder agreement to retire the reactors when their

462 - U.S. House of Representatives, "H.R.3684—Infrastructure Investment and Jobs Act", Public Law No. 117-58, enacted 15 November 2021, see https://www.congress.gov/bill/117th-congress/house-bill/3684/text, accessed 2 September 2022.

463 - 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.

federal operating licenses expire in 2024 and 2025. The proposal prompted DOE to amend in June 2022[464] the program guidance it had recently issued in April 2022,[465] under which Diablo Canyon likely would not have been eligible. In order 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.[466]

On 1 September 2022, the California legislature passed a bill proposed by Governor Gavin Newsom to extend Diablo Canyon's operations and make 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.[467]

The decision may delay the most deliberate and planned nuclear power-plant retirements in the U.S. 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 in 2024 and 2025, 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. The California Public Utilities Commission (CPUC) approved the proposal in 2018, 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 has issued orders to PG&E and all other utilities in the state to procure a total of 22 GW of renewable energy and storage capacity by 2026—the vast majority of which by the time Diablo Canyon-1 is to close in November 2024. 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.[468]

464 - 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.

465 - 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.

466 - Office of Nuclear Energy, "U.S. Department of Energy Extends Application Deadline for $6 Billion Civil Nuclear Credit Program", U.S. DOE, 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", U.S. DOE, 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.

467 - California Senate, "California Senate Bill 846—Diablo Canyon Powerplant: Extension of Operations", passed 1 September 2022, see https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB846, accessed 7 September 2022.

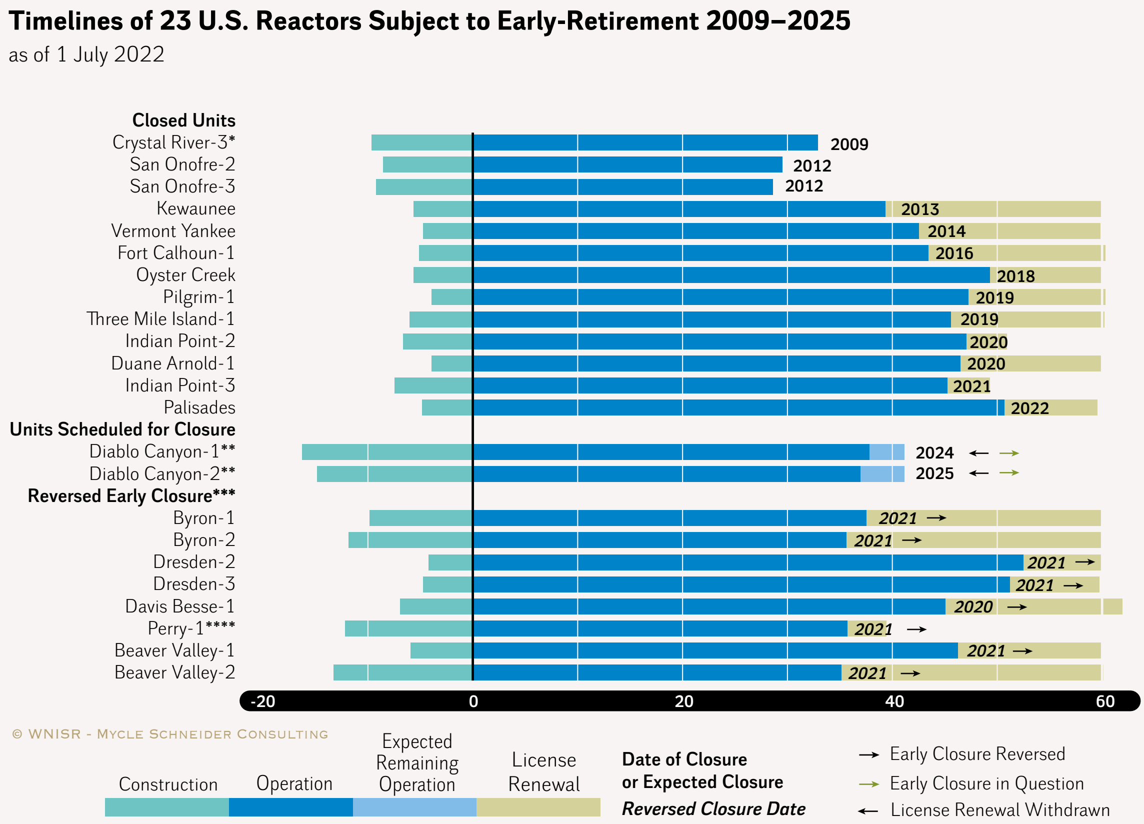
468 - CPUC, "CPUC Orders Historic Clean Energy Procurement To Ensure Electric Grid Reliability and Meet Climate Goals", Press Release, California Public Utilities Commission, 24 June 2021, see https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-orders-clean-energy-procurement-to-ensure-electric-grid-reliability; 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.

The Inflation Reduction Act contains six potential sources of funding and financing for existing and new reactors:

- **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. 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 for annual revenue of 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." 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"[469] receive a 10 percent 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.
- **Funding for DOE Loan Programs Office:** Authorizes an additional US$40–43.6 billion for loan guarantees under DOE's existing program, for which new reactors would be eligible.
- **Availability 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.

469 - Defined as communities with high levels of unemployment where there are brownfield industrial sites or historical dependence on fossil fuel extraction, production, or generation.

Figure 42 · Timelines of 23 Reactors Subject to Early Retirement in the United States



Sources: Various, compiled by WNISR, 2022

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", U.S. Nuclear Regulatory Commission, Updated 9 December 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/crystal-river.html, accessed 8 September 2020.

** Possible deferral of closure until 2029 and 2030

*** 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 Perry Nuclear Power Plant, "Notice of Intent to Submit License Renewal Application", Energy Harbor, addressed to U.S. Nuclear Regulatory Commission, 13 May 2020, see https://www.nrc.gov/docs/ML2013/ML20134H987.pdf, accessed 8 September 2022. Submission is expected in 2023.

As of 1 July 2022, legislation in five states (Connecticut, Illinois, New Jersey, New York and Ohio) had been enacted—with one retraction in Ohio as a result of the FirstEnergy corruption scandal (see below)—which in total provided state subsidies to 18 reactors at eleven nuclear plants. All of these five states have unbundled, retail-choice electricity markets, where generators do not receive cost recovery from state regulatory commissions. In the four states with active nuclear subsidy programs, those reactors account for 16 percent of the utility-scale generating capacity and 19 percent of the U.S. nuclear generating capacity.[470]

As reported previously, central to the future of nuclear power in the PJM Interconnection LLC (PJM) and other wholesale electricity markets are the rules governing how these state

470 - U.S. EIA, "State Electricity Profiles", U.S. Energy Information Administration, 4 November 2021, see https://www.eia.gov/electricity/state/; and U.S. EIA, "Electric Power Annual: Table 4.3. Existing Capacity by Energy Source, 2020 (Megawatts)", 29 October 2021, see https://www.eia.gov/electricity/annual/html/epa_04_03.html, both accessed 5 September 2022.

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 Commission (FERC), which oversees them, have tried to balance the competing interests of different industry segments—principally, the coal, gas, and nuclear industries. RTOs/ISOs are private organizations whose governance is dominated by the commercial interests with the greatest market shares.[471] For instance, in June 2018, FERC invalidated the PJM market rules.[472] The FERC order related to how PJM set the price of capacity it procures through its capacity market, known as the Reliability Pricing Model (RPM). The new FERC rules would have affected how state subsidies, including ZECs, would be considered in the wholesale market. At issue was whether the subsidies being received by utilities for their nuclear plants would be factored into the capacity auction pricing. As reported in previous WNISRs, the legislation passed in four of the five states has been Zero Emission Credits or ZECs.

These instruments are similar in name but different in function from the more well-established system of renewable energy credits (RECs). ZECs in Illinois, New York, and New Jersey are awarded on an uncompetitive, fixed-price basis to single corporations gigawatts of nuclear capacity, representing large shares of the existing state/regional generation supply. In states that have established renewable energy (or portfolio) standards (RES or RPS), contracts for RECs are auctioned to renewable energy projects on a competitive basis, from a fixed pool of credits determined by annually increasing targets for renewable energy consumption. ZECs provide subsidies to help nuclear generators boost profitability and hold onto their market share, whereas RECs provide a competitively priced incentive for the deployment of new renewable technologies at the lowest cost. Both policies are intended to reshape market outcomes, and FERC noted in its 2018 order that "With each such subsidy, the market becomes less grounded in fundamental principles of supply and demand."[473]

In December 2019, FERC released an order[474] directing PJM[475] to significantly expand its minimum offer price rule (MOPR) to mitigate the impacts of state-subsidized resources on the capacity market. The ruling had the potential to undermine renewable energy development and drew sharp opposition from a range of interests, including renewable energy industry

471 - The Federal Energy Regulatory Commission, or FERC, is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity. FERC also regulates natural gas and hydropower projects.

472 - Sonal Patel, "FERC Nixes PJM's Fixes for Capacity Market Besieged by Subsidized Resources", *POWER Magazine*, 5 July 2018, see https://www.powermag.com/ferc-nixes-pjms-fixes-for-capacity-market-besieged-by-subsidized-resources/?printmode=1, accessed 7 July 2020.

473 - FERC, "Order Rejecting Proposed Tariff Revisions, Granting In Part And Denying In Part Complaint, And Instituting Proceeding Under Section 206 Of The Federal Power Act", Docket Nos. EL16-49-000, issued 29 June 2018, p. 3, see https://elibrary.ferc.gov/eLibrary/filelist?accession_number=20180629-4005, accessed 24 August 2021.

474 - FERC, "Order Establishing Just And Reasonable Rate", Docket Nos. EL16-49000 and EL18-178-000, 169 FERC 61,239, issued 19 December 2019, see https://www.pjm.com/-/media/documents/ferc/orders/2019/20191219-el16-46-000-el18-178-000.ashx, accessed 7 July 2020.

475 - Adam Keech, "Capacity Market Minimum Offer Price Rule Order", Vice President of Market Operations, Market Implementation Committee, PJM, 8 January 2020, see https://www.pjm.com/-/media/committees-groups/committees/mic/2020/20200108/20200108-item-04a-ferc-order-on-mopr.ashx, accessed 7 July 2020.

associations, environmental groups, and states with specific RES/RPS policies, which are particularly concerned about the ruling's de-facto support for continued fossil fuel use.[476]

One consequence of the FERC ruling was a delay to the 2021 PJM auction (which are held twice annually). When it was held in June 2021, nuclear generation cleared the most additional capacity compared to the previous capacity auction, with an additional 4,460 MW.[477] Industry analysts noted that Public Service Enterprise Group Inc. (PSEG) and Exelon's Salem plant in New Jersey and PSEG's Hope Creek plant in New Jersey likely secured contracts by appealing for PJM's unit-specific exemption to the MOPR, which allows them to bypass default numbers PJM may assign a resource because of its status as a state-subsidized resource.[478] One explanation for the more successful auction for nuclear plants compared to the previous auction was the impact of the Biden administration's active support for nuclear power.[479] This was despite the 64-percent reduction in the auction price compared to 2018, with PJM confirming that for the period 2022–2023 the price was US$50/MW-day compared to the US$140/MW-day three years ago.[480]

Exelon, in a filing with the U.S. Securities and Exchange Commission, revealed that its Byron, Dresden and Quad Cities nuclear plants in Illinois all failed to sell their power at the PJM auction, losing out to other power plants and energy resources.[481] At the time of the filing, two reactors each at the Byron and Dresden sites were slated to be closed in September and November 2021 respectively, while Quad Cities is in receipt of Illinois state subsidies from 2017-2027. PJM confirmed that the four reactors can retire without putting overall grid reliability at risk,[482] But Exelon retracted the closure plans in September 2021, after Illinois enacted legislation providing US$694 million in subsidies to them over five years.

A proposal from PJM in response to the FERC MOPR ruling was issued on 30 June 2021. Under the PJM proposal, state policies providing out-of-market payments to generating resources, such as nuclear plants, would be recognized as being a legitimate exercise of a state's authority over the electric supply mix. Those policies would not be subject to the MOPR "so long as the policy does not constitute the sale of a FERC-jurisdictional product that is conditioned on

476 - Jeff St. John, "FERC Denies Rehearings on PJM Capacity Orders, in a Blow to States' Renewables Plans", *GreenTechMedia*, 16 April 2020, see https://www.greentechmedia.com/articles/read/ferc-denies-rehearings-on-its-pjm-capacity-rulings-opening-door-for-legal-challenges, accessed 7 July 2020.

477 - Catherine Moorhouse, "Nuclear capacity increases by 4.5 GW in long-delayed 'MOPRed' PJM auction, coal loses 8 GW", *Utility Dive*, 3 June 2021, see https://www.utilitydive.com/news/nuclear-capacity-increases-by-44-gw-in-long-delayed-mopred-pjm-auction/601208/, accessed 11 August 2021.

478 - Ibidem.

479 - Ibidem.

480 - Scott Van Voorhis, "Fate of Illinois nuclear plants in balance after 3 fail to clear PJM auction and subsidy plan stalls", *Utility Dive,* 7 June 2021, see https://www.utilitydive.com/news/fate-of-illinois-nuclear-plants-in-balance-after-pjm-auction-fail-and-stall/601324/, accessed 11 August 2021.

481 - U.S. States Securities and Exchange Commission, "Form 8-K—Current Report", Registrant Exelon Corporation and Exelon Generation Company, 2 June 2021, see https://investors.exeloncorp.com/node/12696/html, accessed 11 August 2021.

482 - *23 WIFR*, "Byron Nuclear Plant scheduled to shut down in Sept., Exelon says", 28 July 2021, see https://www.wifr.com/2021/07/28/byron-nuclear-plant-scheduled-shut-down-sept-exelon-says/, accessed 12 August 2021.

clearing in any RPM [Reliability Pricing Model] auction," the grid operator said in its proposal summary.[483]

A change in leadership at FERC and the retirement of a commissioner after President Biden took office in January 2021 resulted in a deadlock when the commission reviewed PJM's "focused MOPR" proposal.[484] The policy went into effect 90 days later without FERC taking action, effectively defaulting back to the previous rules after three years of market uncertainty and deferred capacity auctions. The proposals from PJM were to be incorporated into the next auction, which was to be held in December 2021, for the period 2023–2024. However, the auction was again delayed when FERC reversed a previous decision affecting the amount of capacity PJM must procure.[485]

While efforts to secure ZEC legislation stalled in Pennsylvania, the decision by the state Governor to join the Regional Greenhouse Gas Initiative (RGGI) has led to the choice to reverse the decision to close Beaver Valley-1 and -2. Plant owner Energy Harbor Corp. notified PJM that it would rescind its March 2018 deactivation notices. The reactors were owned previously by FirstEnergy Solutions (the merchant generation subsidiary of utility holding company FirstEnergy Corp.) which had filed for bankruptcy in 2018. Beaver Valley Units 1 and 2 were scheduled to close in May and October 2021. The RGGI is a cap-and-trade program to limit carbon dioxide emissions from power plants.

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.[486] Pennsylvania issued the emissions regulations necessary to join RGGI in April 2022,[487] but a court injunction prevents their implementation until rulings on legal challenges are issued.[488] Hearings in the cases are scheduled for September and November 2022. The states that are in the RGGI are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.

Prior to enactment of the IIJA and IRA, Exelon announced that it would not close any other reactors in Illinois for at least six more years. The state enacted legislation extending subsidies to the Braidwood-1 and -2, Byron-1 and -2, and Dresden-2 and -3 reactors until 2027.

483 - PJM, "Summary of the Updated PJM MOPR Proposal", 30 June 2021, see https://pjm.com/-/media/committees-groups/cifp-mopr/2021/20210630/20210630-cifp-mopr-pjm-proposal.ashx; and American Nuclear Society, "PJM board okays plan to ease concerns with MOPR ruling", *Nuclear News Wire*, 14 July 2021, see https://www.ans.org/news/article-3067/pjm-board-okays-plan-to-ease-concerns-with-mopr-ruling/; both accessed 11 August 2021.

484 - Ethan Howland, "PJM's 'focused' MOPR takes effect, boosting renewables and nuclear as FERC commissioners deadlock", *Utility Dive*, 30 September 2022, see https://www.utilitydive.com/news/pjm-focused-mopr-takes-effect-ferc-capacity-market/607417/, accessed 2 September 2022.

485 - Ethan Howland, "FERC orders PJM to change reserve market rules, delay capacity auctions", *Utility Dive*, 23 December 2021, see https://www.utilitydive.com/news/ferc-orders-pjm-to-change-reserve-market-rules-delay-capacity-auctions/616556/, accessed 2 September 2022.

486 - 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.

487 - Pennsylvania Department of Environmental Protection, "Pennsylvania Enters the Regional Greenhouse Gas Initiative", Press Release, 22 April 2022, see https://www.media.pa.gov/pages/DEP_details.aspx?newsid=1594, accessed 2 September 2022.

488 - Rachel McDevitt, "Pennsylvania's climate rule paused until trial this fall", *National Public Radio*, 7 July 2022, see https://stateimpact.npr.org/pennsylvania/2022/07/07/pennsylvanias-climate-rule-takes-effect-as-sides-prepare-for-trial-this-fall/, accessed 2 September 2022.

Braidwood-1 and -2 and LaSalle-1 and -2 would be kept in operation through May 2023 to "provide time for the significant logistical and technical planning necessary to ensure a safe and orderly retirement."[489] The Braidwood reactors have secured operational licenses to 2046 and 2047 respectively, while the LaSalle reactors are licensed to 2042 and 2043 respectively. However, Exelon warned that early shutdown would take place "in the event policy changes are not enacted".[490] The bill enacted in September 2021 authorized subsidies worth a total of US$694 million over five years for Braidwood, Byron, and Dresden[491]—more than the study concluded was necessary, but far less than the subsidies enacted in 2016 and those proposed in the federal bills. Exelon committed to keeping all of its Illinois reactors operational through the period in which the subsidies are provided, including the unsubsidized LaSalle reactors.

Reactor Construction

"Part of the risk that we see is that if something else were to happen during the construction between now and when it goes online for commercial operations, we would have to pay that too. ... If we tender and can replace that energy for less than $135 per megawatt hour is the right call for us.
It saves us money."

Jay Stowe, Chief Executive Officer of Jacksonville Electric Authority (JEA), on the utility's decision to request Vogtle co-owner Municipal Electric Authority of Georgia to cap its share of Vogtle construction costs

10 August 2022[492]

The Vogtle Debacle

Only two commercial reactors are currently under construction on a single site in the U.S., the AP-1000 reactors Vogtle-3 and -4 which began construction respectively in March and November 2013.[493] At construction start of Unit 3, the projected cost of the twin-unit project was around US$14 billion, with construction expected to be complete in 2017 and 2018 respectively.[494] The reactors are being built in Burke County, near Waynesboro, in the state of

489 - Scott Van Voorhis, "Fate of Illinois nuclear plants in balance after 3 fail to clear PJM auction and subsidy plan stalls", *Utility Dive*, 7 June 2021, see https://www.utilitydive.com/news/fate-of-illinois-nuclear-plants-in-balance-after-pjm-auction-fail-and-stall/601324/, accessed 11 August 2021.

490 - Ibidem.

491 - 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.

492 - Mike Mendenhall, "JEA's plan for Plant Vogtle savings", *Jacksonville Daily Record*, 2 September 2022, see https://www.jaxdailyrecord.com/article/jeas-plan-for-plant-vogtle-savings, accessed 5 September 2022.

493 - WNISR, "Construction Start on US Vogtle Unit 4", 25 November 2013, see https://www.worldnuclearreport.org/Construction-Start-on-US-Vogtle.html, accessed 20 July 2021.

494 - WNISR, "Construction Start at Vogtle Reactor in the US", 16 March 2013, see https://www.worldnuclearreport.org/Construction-Start-at-Vogtle.html, accessed 7 September 2022.

Georgia, in the southeastern U.S. and are owned by Southern Company (parent company of majority Vogtle plant 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. Those dates have since slipped to March and December 2023. In August 2022, NRC approved Vogtle-3 for initial fuel loading now considered likely to take place in October 2022, and fuel loading for Unit 4 will not occur until at least 2023.[495]

During the past year, the project passed certain construction milestones, but the actual progress in completing construction and meeting the latest startup schedule is still uncertain. As in previous years and as reported in previous WNISR editions, evidence continues to emerge that reveals the enormous scale of the Vogtle project failure. The most recent delays resulted primarily from administrative errors in failing to document over 26,000 inspection records for correcting errors in electrical cable installations.[496] NRC issued violations for the errors in 2021, requiring additional oversight.[497] In granting approval for fuel loading, NRC concluded that Southern Company had satisfied the required inspections, tests, analyses, and acceptance criteria for Vogtle-3 to begin operation.[498]

As of September 2022, construction of Unit 3 was 99 percent complete according to Southern Company, which compares with 98-percent completion as of July 2021 and 81.2 percent as of March 2020.[499] In the case of Unit 4, Southern Company reported that it was 96 percent complete as of September 2022, compared to 84 percent as of July 2021.[500]

Critics of the Vogtle project had long predicted that there would be delays and that costs would be much higher than anticipated.[501] 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 in 2009,[502] which corresponds to a cost of US$5,975/kW (gross), whereas the 2017 estimate of US$23 billion translates to a cost of US$10,300/kW. The revised 2018-estimate was in the

495 - U.S. NRC, "NRC Authorizes Vogtle Unit 3 Fuel Loading and Operation", Press Release No. 22-031, 3 August 2022, see https://www.nrc.gov/reading-rm/doc-collections/news/2022/22-031.pdf, accessed 7 September 2022.

496 - 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.

497 - Jeff Amy, "Nuclear regulators uphold violations at Georgia reactors", *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.

498 - U.S. NRC, "Finding that all Acceptance Criteria are met for the Vogtle Electric Generating Plant, Unit 3, Combined License," see https://www.nrc.gov/docs/ML2029/ML20290A284.pdf, accessed 5 September 2022.

499 - Southern Company, "Building carbon-free nuclear energy Plant Vogtle Units 3 and 4", Undated, see https://www.southerncompany.com/innovation/vogtle-3-and-4.html, accessed 5 September 2022.

500 - Aaron Larson, "Fuel Loading Only Major Milestone Left for Vogtle Unit 3 Nuclear Project", *POWER Magazine*, 30 July 2021, see https://www.powermag.com/fuel-loading-only-major-milestone-left-for-vogtle-unit-3-nuclear-project/, accessed 19 August 2021.

501 - 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.

502 - 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.

range of US$28 billion.[503] As of August 2022, total project costs are reported to have increased to US$30.34 billion, or US$13,581/kW—2.3 times greater than the original approved cost estimate.[504] Those figures do not include US$3.68 billion Westinghouse refunded to the Vogtle owners in 2017.[505] Taking that into account, actual construction cost is now ~US$34 billion, or US$15,219/kW and more than 2.5 times the original approved cost. These costs compare with the Massachusetts Institute of Technology (MIT) 2009-assessment of the prospects for new nuclear power based on overnight costs of US$$_{2007}$4,000/kW.[506]

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 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 translates to Georgia Power 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 using 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.[507] 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 reactors begin generating electricity.[508] As a result of further delays since then, those costs—and thus customer subsidies—will be higher still.

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

503 - 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.

504 - Jeff Amy, "Co-owners sue Georgia Power in $685M Vogtle contract dispute", *Associated Press*, 21 June 2022, op. cit.

505 - Georgia Power, "Toshiba fulfills $3.68 billion parent guarantee obligation for Vogtle nuclear expansion", 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.

506 - John M. Deutch, Charles W. Forsberg, et al., "Update of the MIT 2003 Future of Nuclear Power", MIT Energy Initiative, Interdisciplinary Study, Massachusetts Institute of Technology, 2009, see http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf, accessed 5 August 2019.

507 - Southern Environmental Law Center, "Groups Intervene in Vogtle Cost Proceedings—Georgians Should Not Bear Financial Burden of Georgia Power's Project Mismanagement", Press Release, 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.

508 - Jeff Amy, "Georgia Power seeks $235M boost to pay for nuclear plant", *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.

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.[509]

WNISR2019 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.[510]

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).[511] In 2019, PSC staff had concluded that "at this time the status of the Project is uncertain," with major uncertainties whether the target date of HFTs scheduled for Unit 3 on 31 March 2020 could be achieved.[512] Fuel loading at that time was scheduled for 14 October 2020.

On 30 April 2020, Thomas Fanning, CEO of Georgia Power, stated that, "cold hydro testing is planned to begin in June or July, with hot functional testing beginning in August or September."[513] This schedule changed again, when in June 2020, Southern announced that cold testing would take place "this fall" to then be followed by hot testing.

509 - 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.

510 - Georgia Public Service Commission , "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, see https://www.eenews.net/assets/2020/06/09/document_ew_04.pdf, accessed 3 June 2020.

511 - 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.

512 - Georgia PSC, "In The Matter Of Georgia Power Company's Nineteenth Semi-Annual Vogtle Construction Monitoring Report—Direct Testimony And Exhibits Of Steven D. Roetger and William R. Jacobs, Jr., PhD—On Behalf Of The Georgia Public Service Commission Public Interest Advocacy Staff", Testimony Before The Georgia Public Service Commission, Docket No. 29849, 30 November 2018.

513 - *WNN*, "Major component installed at Vogtle 3", 14 May 2020, see https://world-nuclear-news.org/Articles/Major-component-installed-at-Vogtle-3, accessed 4 July 2020.

Credit-rating agency Standard & Poor'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.[514]

HFT was then supposed to begin in January 2021 but was delayed and considered the primary cause for delay in commercial operation of the reactor. HFT of Vogtle-3 finally began on 25 April 2021 and was planned to be completed within 6–8 weeks.[515] Apparently, Southern Company reported to investors on 29 July 2021 that HFT had been completed.[516]

On 18 May 2021, Southern Company informed the Georgia Public Service Commission that delays in testing of the Vogtle-3 reactor would mean that operation would not start before January 2022, at the earliest.[517] The Commission was told that Unit 3 was 98 percent complete.

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." 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." The company engaged in hot functional testing of the first reactor and encountered more expansion of metal parts as systems were heated up than anticipated. "There's a chance we may need to make some adjustments to the structural supports" Stephen Kuczynski, President and CEO of Southern Nuclear, told Commissioners of the thermal expansion issues. The PSC was then informed that the schedule for operation of Unit 4 was November 2022.[518]

Georgia Power is currently expected to recover approximately US$3.9 billion under the Nuclear Construction Cost Recovery ("NCCR") tariffs imposed on customers during the construction period. "This is nearly double the US$2.1 billion the Company would have collected if the Units had been completed in accordance with the certification schedule of 11 April 2016 and 2017."[519] Under the NCCR, Georgia Power is permitted to request to add US$8.0 billion to its rate base once Units 3 and 4 are in commercial service.

514 - 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.

515 - Georgia Power, "Vogtle Unit 3 begins Hot Functional Testing", Press Release, as published on *PR Newswire*, 26 April 2021, see https://www.prnewswire.com/news-releases/vogtle-unit-3-begins-hot-functional-testing-301276472.html, accessed 21 July 2021.

516 - Southern Company, "Building carbon-free nuclear energy—Plant Vogtle Units 3 and 4", 30 July 2021. op. cit., and *WNN*, "Vogtle in-service dates and cost forecast revised", 29 July 2021, see https://www.world-nuclear-news.org/Articles/In-service-dates-and-cost-forecast-revised-for-Vog, accessed 28 August 2021.

517 - Jeff Amy, "Georgia nuclear plant now delayed until 2022 as costs mount", *Associated Press*, 18 May 2021, see https://apnews.com/article/georgia-government-and-politics-business-af08e2b3402785febe3c7bf24c65cf2c, accessed 7 September 2022.

518 - Ibidem.

519 - Georgia Public Service Commission, "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", Docket No. 29849, 5 June 2020, op. cit.

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.[520] 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. 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, JEA wrote to MEAG requesting that it exercises 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. 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.[521] 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.

The most recent challenge to the Vogtle construction project was in May 2020, when the Blue Ridge Environmental Defense League (BREDL) filed a challenge to an NRC License Amendment request from Southern.[522] BREDL contends that, under the guise of a one-inch change in the seismic gap between two critical walls in the Vogtle Unit 3 reactor, Southern has admitted to a much more serious structural problem, the "dishing" of the nuclear plant's concrete foundation which creates instability.[523] Southern contends that it's just a minor construction flaw, whereas BREDL expert witness, nuclear engineer Arne Gundersen, stated "that the sheer weight of the nuclear island building is causing it to sink into the red Georgia clay."[524] During a preliminary oral hearing of Southern's License Amendment request, the case was heard by the NRC's Atomic Safety and Licensing Board (ASLB) on 1 July 2020. On 10 August 2020, the ASLB issued Memorandum and Order, denying BREDL's intervention,

520 - Jeff Amy, "Co-owners sue Georgia Power in $695M Vogtle contract dispute", *Associated Press*, 22 June 2022, op. cit.

521 - 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.

522 - BREDL, "BREDL And Our Chapter Concerned Citizens Of Shell Bluff File Petition Regarding Plant Vogtle Plant 3 License Amendment And Exemption", Blue Ridge Environmental Defense League, 12 May 2020, see http://www.bredl.org/nuclear/200511_BREDL_Petition_to_Intervene_Vogtle_3.htm; and U.S.NRC, "In the Matter of Southern Nuclear Operating Co.–License Amendment Application for Combined Licenses NPF-91, Vogtle Electric Generating Plant Unit 3—Petition For Leave To Intervene And Request For Hearing By The Blue Ridge Environmental Defense League And Its Chapter Concerned Citizens Of Shell Bluff Regarding Southern Nuclear Operating Company's Request For A License Amendment And Exemption For Unit 3 Auxiliary Building Wall 11 Seismic Gap Requirements, LAR-20-001", Docket No. 52- 025-LA-3, NRC-2008-0252, 11 May 2020, see https://www.bredl.org/pdf6/200511_BREDL_Petition_to_Intervene_Vogtle_3_Docket_52-025-LA-3.pdf, both accessed 4 July 2020.

523 - BREDL, "Residents Fight to Bring Case Against Georgia Nuclear Plant Legal Brief", Press Release, Blue Ridge Environmental Defense League, 15 June 2020, see http://www.bredl.org/press/2020/200615_PR_Reply_Filed_VEGP-3_Plant_Sinking.pdf, accessed 4 July 2020.

524 - Ibidem.

and dismissing the two contentions and terminating the proceeding.[525] On 4 September 2020, BREDL filed with the NRC seeking Commission review of the ASLB decision.[526] NRC denied the petition on 22 December 2020.[527] BREDL filed a motion to reopen the proceeding on 7 December 2020[528] and an amended contention on 28 December 2020,[529] which NRC denied on 15 March 2021.[530]

Vogtle Federal Loan Guarantees

Under the terms of the Department of Energy (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 2010 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.[531]

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

525 - Atomic Safety and Licensing Board, "In the Matter of Southern Nuclear Operating Company, Inc. (Vogtle Electric Generating Plant, Uni 3)—Memorandum and Order (Denying Intervention Petition and Terminating Proceeding)", Docket No 52-°25-LA-3, ASLBP No. 20-967-03-LA-BD01, U.S. NRC, 10 August 2020, see https://www.nrc.gov/docs/ML2022/ML20223A385.pdf, accessed 7 September 2022.

526 - BREDL, "In the Matter of: Southern Nuclear Operating Company License Amendment Application for Combined License NPF-91 Vogtle Electric Generating Plant Unit 3—Blue Ridge Environmental Defense League's Notice of Appeal and Brief in Support of Appeal from the Atomic Safety and Licensing Board Decision Denying Admissibility of Contentions in License Amendment Proceeding", Docket No. 52-025-LA-3, filed with U.S. NRC, 4 September 2020, see https://www.nrc.gov/docs/ML2024/ML20248J166.pdf, accessed 12 August 2020.

527 - U.S. NRC, "Southern Nuclear Operating Company, Inc.; Vogtle Electric Generating Plant, Unit 3; Unit 3 Auxiliary Building Wall 11 Seismic Gap Requirements", Federal Register, 12 January 2021, see https://www.federalregister.gov/documents/2021/01/12/2021-00410/southern-nuclear-operating-company-inc-vogtle-electric-generating-plant-unit-3-unit-3-auxiliary, accessed 5 September 2022.

528 - BREDL, "BREDL and our chapter Concerned Citizens of Shell Bluff file motion to reopen proceeding regarding Plant Vogtle Unit 3", Blue Ridge Environmental Defense League, 17 December 2020, see https://www.bredl.org/nuclear/201207_BREDL_Motion_to_Reopen_Vogtle3_Docket52-025-LA-3.htm, accessed 5 September 2022.

529 - BREDL, "BREDL and our chapter Concerned Citizens of Shell Bluff file Motion to reopen and submit amended contention regarding Plant Vogtle Unit 3", Blue Ridge Environmental Defense League, 29 December 2020, see https://www.bredl.org/nuclear/201228_BREDL_REPLY_Motion_to_Reopen_Vogtle3_Docket52-025-LA-3.htm, accessed 5 September 2022.

530 - U.S. NRC, "CLI-21-06—Memorandum and Order", Docket No. 52-025-LA-3, 15 March 2021, see https://adams.nrc.gov/wba/download?isTbar=false&tabId=advanced-search-pars-tab&viewText=undefined&ids=%5B%7B%22documentId%22%3A%7B%22compound%22%3Afalse%2C%22dataProviderId%22%3A%22ce_bp8os_repository%22%2C%22properties%22%3A%7B%22%24os%22%3A%22ADAMSPublicOS%22%2C%22ce_object_id%22%3A%22%7B92318D3E-C82C-CBDD-8DDA-78367CA00000%7D%22%2C%22%24is_compound%22%3Afalse%7D%7D%7D%5D&docTitle=Commission+Memorandum+and+Order+%28CLI-21-06%29.&action=view&mimeType=application%2Fpdf&actionId=view, accessed 5 September 2022.

531 - 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.

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. [532] The other owners—Georgia Power and MEAG—had secured US$8.3 billion in separate loan guarantees from DOE since 2010, when they were approved by the Obama administration.[533] Both companies confirmed in August 2017 that they were seeking additional loan guarantee funding.

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.[534] A decision on terminating the Vogtle project would raise the prospect of repayment of the previous US$8.3 billion loan to Southern.[535] In April 2019, the DOE provided an additional loan guarantee of US$3.7 billion to Plant Vogtle construction, only the second loan guarantee issued under the Trump administration and the second to Plant Vogtle.[536] This brought the total loan guarantees provided for the Vogtle project by the DOE to US$12.03 billion.[537]

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. This does not appear to have deterred the industry from continuing to engage in significant lobbying and political action even as the Justice Department continued corruption investigations involving nuclear corporations. 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 testimony to the extent of political activity by the industry. In total, ten of the largest nuclear corporations and their major trade groups reported over US$58 million in lobbying expenses at the federal level in 2021.[538]

532 - 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.

533 - Sonal Patel, "DOE Issues Remaining $1.8B in Loan Guarantees for Vogtle Nuclear Reactors", *POWER Magazine*, 24 June 2015, see https://www.powermag.com/doe-issues-remaining-1-8b-in-loan-guarantees-for-vogtle-nuclear-reactors/, accessed 7 September 2022.

534 - 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.

535 - 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.

536 - 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.

537 - 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.

538 - Search of lobbying disclosure reports on https://lda.senate.gov/filings/public/filing/search/, accessed 1 February 2022 for the following clients: Exelon, FirstEnergy, Energy Harbor, Duke Energy, Nextera Energy, Southern Company, Dominion Energy, Dominion Resources, Entergy, PSEG, Vistra, NRG Energy, Nuclear Energy Institute, and Edison Electric Institute.

Fraud Investigation and Prosecutions over V.C. Summer Project

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 past five years. At the time of cancellation, the total costs for completion of the two AP-1000 reactors at V.C. Summer was projected to exceed US$25 billion—about 2.5 times the initial estimate.[539] 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.[540] Under legislation passed by the South Carolina state Legislature in 2007[541]—but strongly opposed by civil society groups—construction costs for the V.C. Summer reactors were to be paid by state ratepayers.[542] When SCANA was taken over by Dominion Energy in January 2019, it "committed to make extensive remedial efforts to redress ratepayers," which was estimated to be approximately US$4 billion.[543] 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.[544] The 8 June 2020 filing made it clear that Dominion will not be prosecuted, with a utility spokesman stating that "We have no further comment regarding this matter or the investigation".[545]

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.[546] Marsh was the first defendant to be sentenced, though 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

539 - 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. 219224, see https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/7195-nn-build-2015.pdf, accessed 5 September 2022.

540 - 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 *The State*, "SCANA conspirators helped Byrne spin lies about nuclear project, document alleges 9 June, 2020", Updated 15 June 2020, see https://www.thestate.com/news/local/crime/article243395241.html, both accessed 6 July 2020.

541 - 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.

542 - 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.

543 - Joniel Cha, "Former Scana executive to plead guilty to fraud over Summer nuclear project", *Nucleonics Week*, 11 June 2020.

544 - 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.

545 - Ibidem.

546 - U.S. Attorney's Office, District of South Carolina, "Former SCANA CEO Sentenced to Two Years for Defrauding Ratepayers in Connection with Failed Nuclear Construction Project", 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 5 September 2022.

financial troubles at the nuclear project from the public, from regulators, and from investors in the publicly traded utility.

The Director of Savannah River Site Watch (SRS Watch) Tom Clements stated that "The [US]$5 million fine is really like a traffic ticket to him… I assume he (Marsh) is going to suffer for two years in prison, but he really deserves a much longer prison sentence for what he's done to the state of South Carolina," said Clements, who predicted more people will eventually be charged.[547]

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."[548] On 10 June 2021, Churchman pleaded guilty to the felony offence of lying to the FBI.[549]

A parallel legal case, brought by the Securities and Exchange Commission (SEC) against SCANA executives, was settled in December 2020. They were accused of civil fraud in 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, requires 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.[550]

Acting U.S. Attorney Rhett DeHart stated in June 2021, "It's clear that our investigation into the V.C. Summer nuclear debacle didn't end with the SCANA case," he said. "Our office is committed to seeing this investigation through and holding all individuals and companies who participated in this fiasco accountable."[551]

The pace of developments in the investigation appears to have slowed, with no further indictments, convictions, or sentences since October 2021. On 9 May 2022, a procedural ruling was reported to clear the way for the trial of former Westinghouse Vice President Jeff Benjamin in a sixteen-count felony criminal indictment.[552] 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 may begin as soon as October 2022 as a result of the ruling.

547 - Ibidem.

548 - 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.

549 - U.S. Attorney's Office, District of South Carolina, "Westinghouse Director During Nuclear Debacle Pleads Guilty in Federal Court to Making False Statement to FBI", U.S. Department of Justice, 10 June 2021, op. cit.

550 - 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.

551 - Scott Judy, "Who's the Next Target in Feds' Nuke Plant Fraud Investigation?", *Engineering News Record*, 24 June 2021, see https://www.enr.com/articles/51918-whos-the-next-target-in-feds-nuke-plant-fraud-investigation, accessed 20 July 2021.

552 - 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.

Ohio Corruption Scandal and Nuclear Subsidy Legislation

"FirstEnergy's core values and behaviors include integrity, openness, and trust. As an organization, we are redoubling our commitment to live up to these values and the standards that we know our stakeholders expect of us."

Steven E. Strah, FirstEnergy president and chief executive officer

22 July 2021.[553]

In July 2020, the speaker of the Ohio House of Representatives, Larry Householder, was arrested by the FBI on charges of racketeering. It was alleged at the time that he 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.[554]

As a result of the leadership role of Householder, in 2019, legislation House Bill 6 (HB6)[555] was passed and FirstEnergy's Davis-Besse and Perry reactors 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.[556] Householder pleaded not guilty. In the two years since, the scandal has escalated, leading to the admission of guilt by FirstEnergy, and the enactment of a bill in 2021 repealing the nuclear subsides and a profiteering ratemaking provision in HB6, while leaving a smaller subsidy program for two coal plants and provisions that effectively ended energy efficiency and renewable energy standards in place.[557]

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."[558]

553 - FirstEnergy, "FirstEnergy Reaches Agreement to Resolve Department of Justice Investigation", 22 July 2021, see https://firstenergycorp.com/newsroom/news_articles/firstenergy-reaches-agreement-to-resolve-department-of-justice-i.html, accessed 12 August 2021.

554 - 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.

555 - 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.

556 - 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.

557 - 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.

558 - 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.

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."[559]

On 16 November 2020, FBI agents raided the home of PUCO Chairman Sam Randazzo.[560] 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.[561] PUCO, also in November 2020, began an audit of FirstEnergy to see whether the company broke any laws or regulations regarding its interactions with an ex-subsidiary while the companies pushed to secure HB6.

On 29 December 2020, the Ohio Supreme Court ordered a halt to electric utilities collecting monthly fees under HB6.[562]

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.[563] The Ohio Consumers' Counsel had called on the Ohio PUCO to order FirstEnergy to "remedy what would be a miscarriage or perversion of justice" was 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.[564]

On 31 March 2021, Ohio Governor DeWine signed House Bill 128, which permanently cancels nuclear power subsidies paid under HB6.[565] FirstEnergy, also on 31 March 2021, reversed its previous position and agreed to refund US$26 million to consumers for charges it collected through HB6.

On 22 July 2021, it was announced that FirstEnergy 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

559 - Ibidem.

560 - 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, accessed 12 August 2021.

561 - 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/, accessed 12 August 2021.

562 - *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.

563 - Mark Gillespie, "FirstEnergy refusing to return subsidy cash to customers", *Associated Press*, 20 March 2021, see https://apnews.com/article/akron-ohio-archive-utilities-d2d8b22e574437d91b247b3e693252ef, accessed 12 August 2021.

564 - Ibidem.

565 - 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 bailout for two nuclear plants. The U.S. Department of Justice detailed that in court filings, 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.
>
> (…)
>
> FirstEnergy Corp. further acknowledged that it paid $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.[566]

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.[567] 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.

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 (which was spun off and reconstituted through bankruptcy as Energy Harbor) donated US$61 million to Generation Now.[568] Householder led efforts to pass HB6 to bail out the nuclear plants and bankrolled a counter campaign to stop a ballot initiative that would have challenged HB6. 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.

566 - 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.

567 - Scott Noll, "FirstEnergy to pay $230M in settlement in Ohio bribery case", *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.

568 - Laura A. Bischoff and Jessie Balmert, "FirstEnergy charged in Ohio bribery scheme, agrees to deferred prosecution settlement for $230 million", *Cincinatti Enquirer*, 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.

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.[569] 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.[570] In July 2020, prosecutors with the US Attorney's Office for the Northern District of Illinois announced charges against the defendants and a deferred prosecution agreement (DPA) with Exelon subsidiary Commonwealth Edison (ComEd).[571] 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.[572] The charges involve jobs and contracts Exelon gave to associates of House Speaker Madigan, from 2011–2019. Specifically, the investigation centers 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 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 estimates ComEd collected US$4.7 billion in excess revenue from 2011–2019.[573]
- **The 2016 Future Energy Jobs Act,** 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. Householder played the key role in blocking legislation Exelon opposed and in orchestrating the FEJA compromise.

The investigation culminated in the indictment of former Illinois House Speaker Michael Madigan on 2 March 2022.[574] 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.

569 - 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.

570 - 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.

571 - U.S. Attorney's Office, 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", 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.

572 - U.S. Attorney's Office, 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.

573 - 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.

574 - U.S. Attorney's Office, Northern District of Illinois, "Former Illinois Speaker of the House Indicted on Federal Racketeering and Bribery Charges in Connection With Alleged Corruption Schemes", 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.

Under a 2 August 2022 procedural ruling, Madigan's defense must file pre-trial pleadings by 1 February 2023.[575] The trial will not begin until later in 2023, at the earliest.

Conclusion

The number of reactors and annual nuclear generation continued to decline in the U.S. in 2021-22. With the closure of Palisades in May 2022, there were 92 commercial reactors operating as of mid-2022. Generation declined by 1.5 percent in 2021 and nuclear's share of commercial electricity generation fell from 19.7 percent to 18.9 percent, its lowest level since the peak of 22.5 percent in 1995.

While construction of Vogtle-3 and -4 continued, so did cost overruns and schedule delays. Total project costs have now topped US$30 billion, with co-owners announcing their intent to cap their investments and, in the cases of Oglethorpe and MEAG, filing legal claims disputing the distribution of recent cost increases. The NRC approved first fuel loading for Unit 3, expected to start in October 2022. Grid connection dates for Vogtle-3 and -4 are now projected for March 2023 and 4Q2023, respectively.

Since WNISR2021 was published, the nuclear subsidy trend has continued. Illinois enacted a relatively modest, five-year subsidy for six reactors in September 2021. However, the U.S. Congress has recently enacted significant subsidies and financing measures from which the nuclear industry stands to benefit. In November 2021, the Infrastructure Investment and Jobs Act included US$6 billion for a Civil Nuclear Credit grant program for existing reactors, and US$3.2 billion in grants for new reactor demonstration projects. In August 2022, the Inflation Reduction Act (IRA) included several provisions. A tax credit program for existing reactors may total US$30 billion or more over the next decade. There are also additional tax credits and loan guarantees for new reactors, as well as a new loan guarantee program for which existing reactors may be eligible.

Three major corruption and fraud investigations involving both new reactors and nuclear subsidies continued in 2021–2022. Significant developments include the indictment of former Illinois House Speaker Michael Madigan in the corruption investigation focusing on Exelon, and the initiation of trial proceedings for former Westinghouse executive Jeff Benjamin in the Summer-2 and -3 fraud investigation, which may begin in October 2022.

575 - Jason Meisner and Ray Long, "Judge grants defense until next year to file motions in racketeering case against ex-Speaker Michael Madigan", *Chicago Tribune*, 2 August 2022, see https://www.chicagotribune.com/news/criminal-justice/ct-michael-madigan-michael-mcclain-racketeering-case-status-hearing-20220802-3t3mhvc44fcqldkkrb4qrd3zjy-story.html, accessed 5 September 2022.

FUKUSHIMA STATUS REPORT

OVERVIEW OF ONSITE AND OFFSITE CHALLENGES

Introduction

"Slow but steady" appears to be an appropriate description of the decommissioning process of the Fukushima Daiichi nuclear plant. Removal of spent fuel from Unit 1 and Unit 2 has not started yet. Investigations of fuel debris using specially designed robots inside the reactors 1, 2, and 3 continues and is making some progress, but there is still no clear prospect in dealing with the debris. For management of contaminated water, an IAEA expert team visited the Fukushima site and published a report on the release of treated water containing tritium and other radionuclides. The government plans to start the release to the sea next year, while public opposition remains strong. In June 2022, for the first time since the beginning of the disaster, some sections of the "difficult-to-return" areas were considered "safe to return". But still, many residents have not returned and legal disputes over responsibility for the accident and compensation of victims continue.

Onsite Challenges[576]

Current Status of the Fukushima Daiichi Reactors

Due to the continuous injection of water into Fukushima Daiichi Units 1–3, the temperatures of the Reactor Pressure Vessel (RPV) and the Primary Containment Vessel (PCV) were maintained within the range of approx. 15–30 degrees Celsius. Data gathered at monitoring posts at site boundaries between 30 March and 25 April 2022 showed 0.336–1.078 microSievert per hour (µSv)/h. As the radiation dose inside the reactor buildings is still extremely high, it is not 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.

On 13 April 2022, drilling started to install an anchor in the reactor building of Unit 1. The anchor is designed to stabilize the large cover to be installed over the unit prior to spent fuel removal. In order to minimize radiation exposure to the workers, remotely operated anchor drilling equipment has been used.

At Unit 2, ground improvement work preparing for the installation of the fuel removal gantry started on 28 October 2021 and was completed on 19 April 2022.

576 - 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", METI, 21 April 2022, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/mp202204.pdf, accessed 14 June 2022.

Spent fuel removal from the pools is planned to start around FY 2024–2026 at Unit 2, and around FY 2027–2028 at Unit 1. It is currently expected that all spent fuel from both units will be removed by 2031.[577]

A magnitude 7.4 earthquake occurred on 16 March 2022 in the same offshore area as the Great East Japan Earthquake in 2011. On 17 March 2022, TEPCO reported that the water level in the reactor pressure vessel of Unit 1 had dropped by 20 centimeters (cm), and a robotic probe on 22 March 2022 found the water had fallen to a level 40 cm lower than usual. Water levels also dropped at Units 1 and 3 following a large earthquake in February 2021. In order to maintain water levels, the water injection rate was increased.[578] On 29 March 2022, TEPCO confirmed that the water had reached the necessary levels.

Internal investigation of fuel debris inside the reactor vessels of Unit 1, originally scheduled to start in FY 2019, was then planned to start on 12 January 2022, but again postponed to 4 February 2022 due to malfunctioning of the remotely operated vehicle (ROV). The investigation was finally suspended due to transmission loss of the mounted camera and other parts of the machine.

Analysis of fuel debris samples taken from the inside of the pipe for joint standby gas treatment process (SGTS) for Units 1 and 2—assumed to be the main gas transport route during the containment vent at the time of the accident—has resulted in limited useful for the investigation of the course of the accident.

According to a recent study published in the *Journal of Hazardous Materials* by a team of scientists from Japan, France, Finland, and the U.S., most of the control rod boron remains in at least two of the damaged reactors (Units 2 and 3). This means that there will be less likelihood of a "criticality accident" during the removal of debris from the reactor.[579] However, at present, there is no clear prospect when and how fuel debris could be removed from the damaged reactors.

Contaminated Water Management

Through various measures introduced by TEPCO, the generation of contaminated water has been gradually decreasing. The measures introduced include the pumping of water by sub-drains, the construction of land-side frozen walls, and rainwater-infiltration prevention measures including repairing damaged portions of building roofs etc. The amount of contaminated water generation within FY2021 declined to approx. 130 m^3/day from over 500 m^3/day before taking those measures. This means that still almost every week a new 1,000 m^3 tank is still needed.

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 radioactive substances except tritium, treated water is being stored in tanks.

577 - METI, "Status Update of Fukushima Daiichi Commissioning", Ministry of Economy, Trade and Industry, March 2022, p. 7, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/1f_status_20220307.pdf, accessed 14 June 2022

578 - Yu Fujinami and Tsuyoshi Kawamura, "Water level kept falling at reactor in Fukushima after earthquake", *The Asahi Shimbun*, 23 March 2022, see https://www.asahi.com/ajw/articles/14579691, accessed 14 June 2022.

579 - University of Helsinki, "Can reactor fuel debris be safely removed from Fukushima Daiichi?", *Tech Explore*, 25 January 2022, see https://techxplore.com/news/2022-01-reactor-fuel-debris-safely-fukushima.html, accessed 14 June 2022.

As of 9 June 2022, about 1.3 million m^3 of treated water is stored in 1,020 tanks. There are currently 1,061 tanks on site. Reportedly, as of 28 July 2022, capacity saturation had reached 96 percent, and without adding any further storage, the tanks would be full by summer or fall of 2023.[580]

27 tanks store water that has undergone strontium (Sr) removal. Strontium removal is carried out by cesium-absorption in three stages.

ALPS is supposed to separate most of the radionuclides except tritium, so the concentration of other radionuclides remain below regulatory standards. However, due to malfunction and lower-than expected ALPS performance, of 1.3 million m^3 only 32 percent (about 412,000 m^3) satisfies regulatory standards and two thirds (about 855,000 m^3) of treated water need to be re-purified.[581] (See Figure 43)

According to a government decision of 13 April 2021, treated water containing tritium will be discharged into the ocean. TEPCO has been preparing the discharge plan as follows.[582]

- **Measurement and confirmation**. The concentration of tritium, carbon-14, and 62 other radionuclides will be measured, and a third party should confirm that all concentrations remain below the regulatory limits for discharge.
- **Dilution**. The treated water will be diluted further (at least 100 times) so that the tritium concentration after dilution should be below 1,500 becquerel per liter (Bq/L)[583]. Measuring results will be made public promptly.
- **Discharge**. Treated water will be discharged via an undersea tunnel (about 1 km) in order to avoid recirculation into the seawater (cross-contamination) taken in for cooling purposes. In the near term, discharge amounts will be within the threshold of 22 trillion Bq per year, which was the regulatory limit for Fukushima Daiichi before the accidents. This amount will be reviewed as needed.
- **Abnormal Events**. Discharge will be stopped if an abnormality is found, and two emergency isolation valves shall be installed for emergency shutdown.

On 18 May 2022, Nuclear Regulation Authority (NRA) endorsed TEPCO's plan to discharge treated water into the sea. The NRA concluded that the water discharge will help TEPCO secure space for facilities needed for future decommissioning work and lower overall risks to the Fukushima plant.[584]

580 - *The Asahi Shimbun*, "TEPCO pushes back timeline for storage tanks at Fukushima plant", 28 April 2022, see https://www.asahi.com/ajw/articles/14609795, accessed 8 August 2022.

581 - TEPCO Holdings, "Treated Water Portal Site", as of 9 June 2022, see https://www.tepco.co.jp/en/decommission/progress/watertreatment/alps01/index-e.html, accessed 14 June 2022.

582 - TEPCO, "Installation of New ALPS Treated Water Dilution/Discharge Facilities and the Related Facility", 27 January 2022, see https://www.tepco.co.jp/en/hd/decommission/information/committee/pdf/2022/alps_22012701-e.pdf, accessed 4 August 2022.

583 - This is reported to be 1/40 of regulatory standard for discharged water. But that statement is somewhat misleading. As the treated water contains other nuclides, 1,500 Bq/L is a regulatory standard for discharge of contaminated water at Fukushima plant, considering the sum of possible exposures from other radioactive nuclides.

584 - *Nikkei Asia*, "Japan nuclear regulator Oks plan to release treated Fukushima water: Fishery groups fear reputational damage: China, South Korea also express concerns", 18 May 2022, see https://asia.nikkei.com/Business/Energy/Japan-nuclear-regulator-OKs-plan-to-release-treated-Fukushima-water, and TEPCO, "Nuclear Regulation Authority Compiles Draft of Review Report", 18 May 2022, see https://www.tepco.co.jp/en/hd/newsroom/announcements/archives/2022/20220518_01.html, both accessed 16 June 2022.

Before TEPCO can begin implementing the discharge plan, local consent will be needed based on a pledge made in 2015 that TEPCO would not discharge the water "without gaining an understanding from stakeholders"[585]. On 5 April 2022, a major fisheries group in Japan told Prime Minister Kishida that they still firmly oppose the discharge of treated water into the sea due to concern over negative impact on the industry.[586]

In order to reduce public concern over the discharge plan, the Japanese government asked the IAEA to review the overall plan. The IAEA Task Force published its first report on 29 April 2022, saying: "TEPCO successfully incorporated prevention measures in the design of the [water dilution and discharge] facility as well as in the associated operating procedures… the doses to the assumed representative person are expected to be very low and significantly below the dose constraint set by the regulatory body (NRA)."[587]

International concerns over the discharge plan remain. In July 2021, the Pacific Islands Forum Ministers Meeting declared themselves "deeply concerned over the implications" and noted

> the concerns surrounding the seriousness of this issue in relation to the potential threat of further nuclear contamination of our Blue Pacific and the potential adverse and transboundary impacts to the health and security of the Blue Pacific Continent, and its peoples over both the short and long term.[588]

In April 2022, South Korean Representative Seo Sam-seok stated: "The contaminated water released into the ocean will spread across the entire Pacific Ocean in 10 years and affect almost all of our sea".[589]

The Japanese Government also tried to reduce international concerns over the discharge of treated water, by sending out monthly information sheets and by holding video conferences for foreign missions in Japan. For example, on 10 May 2022, the Japanese government held a video conference for all diplomatic missions in Tokyo[590], and on 2 June 2022, a video conference was held for the Government of the Republic of Korea.[591] Despite such efforts, there is no palpable indication that international concerns are disappearing.

585 - *Asahi Shimbun*, "Japan to release 'treated water' from Fukushima plant into the sea", 13 April 2021, see https://www.asahi.com/ajw/articles/14329854, accessed 16 June 2022.

586 - *Kyodo News*, "Fisheries group conveys to PM opposition to Fukushima water release", 5 April 2022, see https://english.kyodonews.net/news/2022/04/493cfc399008-fisheries-remain-opposed-to-fukushima-water-discharge.html, accessed 16 June 2022.

587 - TEPCO, "Release of Results from International Atomic Energy Agency (IAEA) Review of Safety Related Aspects of the Handling of ALPS Treated Water", Press Release, 2 May 2022, see https://www.tepco.co.jp/en/hd/newsroom/announcements/archives/2022/20220502_01.html; and IAEA, "IAEA Releases First Report on Safety of Planned Water Discharge from Fukushima Daiichi Site", Press Release, 29 April 2022, see https://www.iaea.org/newscenter/pressreleases/iaea-releases-first-report-on-safety-of-planned-water-discharge-from-fukushima-daiichi-site; both accessed 16 June 2022.

588 - Pacific Islands Forum, "2021 Forum Foreign Ministers Meeting (FFMM) Outcomes", Pacific Islands Forum Secretariat, 27 July 2021, see https://www.forumsec.org/2021/07/30/2021-forum-foreign-ministers-meeting-ffmm-outcomes/, accessed 24 June 2022.

589 - CGTN, "Int'l community voices concerns over Japan's wastewater release plan", 14 April 2022, see https://news.cgtn.com/news/2022-04-14/Intl-community-voices-concerns-over-Japan-s-wastewater-release-plan-19ehhSrxsg8/index.html, accessed 21 June 2022.

590 - METI, "Briefing Session on the Current Status of Advanced Liquid Processing System (ALPS) Treated Water at Fukushima Daiichi Nuclear Power Station", Ministry of Economy, Trade and Industry, 10 May 2022, see https://www.meti.go.jp/english/press/2022/0510_001.html, accessed 16 June 2022.

591 - METI, "Video Conference Briefing Session to the Government of the Republic of Korea on the Current Status of Advanced Liquid Processing System (ALPS) Treated Water at TEPCO's Fukushima Daiichi Nuclear Power Station", Press Release, 2 June 2022, see https://www.meti.go.jp/english/press/2022/0602_001.html, accessed 16 June 2022.

Worker Exposure Trend

TEPCO publishes data on worker exposure every month since the Fukushima accidents began. According to the latest report for FY2021 (April 2021–March 2022),[592] average dose rate for TEPCO employees (1,001 employees) was 0.85 mSv, while the average dose rate for contractors (5,860 contractors) was 2.77 mSv, resulting in the total average of 2.51 mSv. The maximum estimated dose in FY2021 for a TEPCO employee was 13.10 mSv while that for contractors was 17.45 mSv. As illustrated above, contractors typically receive about three to four times higher radiation doses than TEPCO employees. The average exposure for the first year (FY2011) was exceptionally high for TEPCO employees, but contractors received higher doses since FY2012 and afterward. Contractors constantly received higher doses for maximum exposure since FY2011 through FY2021 (see Figure 44). There are no epidemiological studies on worker health post-3/11.

Offsite Challenges

Current Status of Evacuation

As of March 2022, 32,404 residents of Fukushima Prefecture are still living as evacuees, the number decreased from a peak of 164,865 in May 2012.[593]

"32,404 residents of Fukushima Prefecture are still living as evacuees."

On 12 June 2022, the evacuation order was lifted for a district designated as "difficult-to-return" zone (an area with high level of radiation, meaning higher than 50 mSv per year) for the first time since the disaster began in 2011. Residents of Noyuki district, about 20 percent of the village called Katsurao, were forced to evacuate after the accident. Village officials say 82 people are registered as residents but only eight people from four households expressed an interest in returning.[594] On 30 June 2022, the evacuation order was also lifted for the first time for a part of a town, Okuma, which hosts the Fukushima nuclear power plant. The areas were designated as "Special Zones for Reconstruction and Revitalization (SZRR)" and received special government funding.[595]

As of February 2022, in the case of towns where the evacuation order was lifted for the whole municipal territory, rates of return have been relatively high; for example, Tamura City 84.6 percent, Naraha Town 62.2 percent, Kawauchi Village 82.6 percent. But for those where evacuation orders were only partially lifted the rate of return has been much lower; for

592 - TEPCO Holdings, "Evaluation of the exposure dose of workers engaged in radiation work at the Fukushima Daiichi Nuclear Power Station", 28 April 2022, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/exposure/pdf/2022/exposure_20220428-e.pdf, accessed 16 June 2022.

593 - Fukushima Prefecture official statistics, March 2022, see https://www.pref.fukushima.lg.jp/site/portal/list271.html, accessed 4 August 2022.

594 - *NHK News*, "Evacuation order lifted in part of Fukushima 'difficult-to-return' zone", 12 June 2022, see https://www3.nhk.or.jp/nhkworld/en/news/20220612_11/, accessed 16 June 2022.

595 - *The Mainichi*, "Evacuation order lifted in Fukushima nuclear plant town after 11 yrs", 30 June 2022, see https://mainichi.jp/english/articles/20220630/p2g/00m/0na/029000c, accessed 4 August 2022.

example, Namie Town 11.2 percent, Iidate Village 29.6 percent, Tomioka Town 15.2 percent, Okuma Town 3.6 percent.[596]

Food Contamination

Nationwide inspections for food contamination continue, with a total of 41,361 samples analyzed in FY2021, according to data published by the Ministry of Health and Welfare, of which 157 samples (0.38 percent) exceeded the legal limits.[597,598] In Fukushima Prefecture, 42 samples out of 14,053 (0.30 percent) were found to exceed legal limits, of which 29 were wild animal meat (wild boar, bear and pheasant) and only three samples out of 4,390 fishery products monitored (0.07 percent) were exceeding legal limits. A surprising phenomenon is that in some other prefectures with much smaller numbers of samples, excessive contamination has a significantly higher share. For example, in Gunma Prefecture, only 842 samples were taken (2 percent of national total) but 33 were found exceeding limits (21 percent of national total). It is unclear, whether the post-3/11 food monitoring program is really representative.[599]

On 8 February 2022, it was reported that Taiwan would relax a ban on Japanese food imports. Taiwan has banned imports of food products from five prefectures in Japan following the Fukushima accidents. Taiwan cabinet spokesperson said that the government had decided to make a "fair adjustment" to its ban, as so many countries have already lifted restrictions.[600] On 29 June 2022, the U.K. government announced that it would also lift food import restrictions from Japan.[601] Of the 54 countries that began imposing import restrictions (e.g. banning Japanese food without certificate of origin or certificate of analysis for radioactivity) after the beginning of the disaster, as of February 2022, 14 countries continued implementing some additional import regulations for "vegetables and fruits", 12 countries for "fishery products", and five countries for "rice" and "tea".[602]

596 - New Fukushima Revitalization Promotion Headquarters, "Steps for Reconstruction and Revitalization in Fukushima Prefecture", Fukushima Prefecture, 28 March 2022, see https://www.pref.fukushima.lg.jp/uploaded/attachment/518129.pdf, accessed 22 June 2022

597 - The standard value established by the MHLW: 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.

598 - Ministry of Health, Labor and Welfare, "Sum up of radionuclides monitoring data reported in FY2021 (Up-to-date Report as of 31 March 2022)", Government of Japan, as of March 2022, see https://www.mhlw.go.jp/english/topics/2011eq/dl/Sum_up_March_2022.pdf, accessed 6 August 2022.

599 - Thirty-five years after the Chernobyl disaster was triggered, in southern Germany, wild game and mushrooms are still found contaminated with caesium-137 to several times the legal limits for sales. The government of Saxony still requires all wild boar hunted for sale to be tested for caesium-137; in 2014, one in three boars was still found too radioactive to consume. See WNISR2021, "Chernobyl—35 Years After the Disaster Began", https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2021-HTML.html#_idTextAnchor105.

600 - *Reuters*, "Taiwan to relax Japan nuclear disaster-related food import ban", as published in *Asahi Shimbun*, 8 February 2022, see https://www.asahi.com/ajw/articles/14543355, accessed 18 June 2022.

601 - Ministry of Foreign Affairs of Japan, "Lifting of Import Restrictions on Japanese Food Products by the United Kingdom", Government of Japan, 29 June 2022, see https://www.mofa.go.jp/press/release/press4e_003140.html, accessed 5 August 2022.

602 - Export and International Affairs Bureau, "Lifting of the Import Restrictions/Measures on Japanese Food Following the Accident of TEPCO Fukushima Daiichi Nuclear Power Station (55 Countries and Regions)", Ministry of Agriculture, Forestry and Fisheries, Government of Japan, February 2022, see https://www.maff.go.jp/j/export/e_info/pdf/thrm_en.pdf, accessed 18 June 2022.

Decontamination and Contaminated Soil

The decontamination work for the Special Decontamination Area of Fukushima Prefecture under the direct control of the national government[603] was completed in March 2018, and the decontamination work for relevant municipalities including the rest of Fukushima Prefecture[604] 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 (15 percent) of the overall contaminated land area.[605]

The biggest issue is what to do with the huge amount of contaminated soil shipped to provisional storage sites. The government designated a total of 1,600 ha of area as "interim storage site", and as of May 2022, close to 80 percent of the area (1,273 ha out of 1,600 ha) had been purchased from some 1,800 local landowners for the establishment of a storage facility.[606] As of the end of May 2022, a total of about 13 million m³ of contaminated soil had been transferred to such interim storage facilities.[607]

The law stipulates that the government is responsible for disposing of the waste at a final disposal site outside Fukushima Prefecture, to be carried out by a company wholly owned by the government within 30 years after starting the interim storage of the waste.[608] However, at present, the government has taken no specific action towards final disposal of contaminated wastes generated due to the Fukushima disaster. The government plans to reuse some of the contaminated soil which was qualified as "below regulatory standards" and started the demonstration program. It plans to issue guidelines by FY 2024. But not a single prefecture backs such reuse plan.[609] It shows that there is still a lack of public trust in the government plans. Still, as of March 2022, 830 locations in six municipalities in Fukushima are hosting "temporary" storage sites for 8,460 m³ of contaminated soil waiting for shipping to an interim storage site. As reported by *Asahi Shimbun*, a key reason for the repeated delays is that "new houses were built on land where contaminated soil was buried as negotiations over storage sites in many communities dragged on. This accounts for about 50 percent of the cases cited by municipalities in a survey by the prefectural government last September [2021]".[610]

603 - A high dose area within a 20km radius of the power plant, located around the difficult-to-return zone.

604 - It covers all eight prefectures, including Fukushima Prefecture, except for the Special Decontamination Area managed by the government.

605 - 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/; 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.

606 - Ministry of the Environment, "Chukan chozo shisetsu no gaiyou" ["Outline of Interim storage facilities"], Undated (in Japanese), Government of Japan, see http://josen.env.go.jp/chukanchozou/about/#section03, accessed 18 June 2022.

607 - Ministry of Environment, "Jokyo dojo nado no yuso" ["Transportation of contaminated land"], Government of Japan, as of June 2022 (in Japanese), see http://josen.env.go.jp/chukanchozou/transportation/index.html, accessed 18 June 2022.

608 - Ministry of Internal Affairs and Communications, "中間貯蔵・環境安全事業株式会社法 ・ 平成十五年法律第四十四号", ["Japan Environmental Storage & Safety Corporation Act"], Government of Japan, August 2015 (in Japanese), see https://elaws.e-gov.go.jp/document?lawid=415AC0000000044, accessed 4 May 2021.

609 - *Asahi Shimbun*, "Survey: Not a single prefecture backs reuse of radioactive soil", 28 March 2021, see https://www.asahi.com/ajw/articles/14311546, accessed 18 June 2022.

610 - *Asahi Shimbun*, "Radioactive waste stuck at 830 sites with nowhere to go", 3 March 2022, see https://www.asahi.com/ajw/articles/14562951, accessed 21 June 2022.

Health of Residents, Legal Cases, Compensation

There are a large number of legal cases related to the Fukushima disaster (for background, see Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accidents in WNISR2021) including the following recent ones:

- In January 2022, a group of six men and women, aged between 17 and 27, diagnosed with thyroid cancer as children, filed a class action suit against TEPCO, seeking US$5.4 million in compensation. This is the first such case which seeks to clarify the relationship between illnesses developed by residents from the vicinity of the Fukushima Daiichi power plant and the 3/11 nuclear disaster. Due to the treatments of thyroid cancer (reportedly, two of the persons had one side of their thyroid removed and four are planning or undergoing radiation therapy), they had to drop out of school or college. They argued that the cancer prevented them from having a normal education or employment as well as marriage and a family life. The Japanese government position on this issue is that there is no causal link between exposure to radiation from the accident and the thyroid cancer developed among children living near the Fukushima plant.[611] The position is highly controversial (for background, see Health Effects of the Fukushima Daiichi Nuclear Power Plant Disaster in WNISR2021).
- On 4 March 2022, Japan's Supreme Court ordered TEPCO to pay compensation of 1.4 billion yen (US$12 million) to about 3,700 people whose lives were heavily impacted by the Fukushima disaster, equating to an average payout of about 380,000 yen (US$3,290) per plaintiff. This is the first Supreme Court decision on accident compensation.[612]
- Following the March ruling, on 10 June 2022, the Supreme Court dismissed claims that the Japanese Government is also responsible for the accident and should therefore pay compensation to these 3,700 people. The decision by the Supreme Court was the first one to judge potential government responsibility for the accident. The decision covered four lawsuits filed in Fukushima, Gunma, Chiba, and Ehime Prefectures.[613]
- On 2 June 2022, the Koriyama branch of the Fukushima District Court ordered TEPCO to pay a total of 73.5 million yen (around US$566,000) to current and former residents of Tamura City. But the 525 plaintiffs, who sought 11 million yen per person (about US$85,000 per person) from TEPCO as well as the Japanese Government, are considering an appeal to higher court, as the court did not acknowledge the responsibility of the government, similar to the decision by the Supreme Court described above.[614]
- On 13 July 2022, the Tokyo District Court ordered four former executives of TEPCO to pay 13 trillion yen (US$95 billion) in damages to the operator of the Fukushima Daiichi nuclear power plant. The case was brought by TEPCO shareholders, and the ruling was the first time a court has found former executives responsible for the nuclear accident. The

611 - Thisanka Siripala, "Fukushima Disaster's Impact on Health will be Challenged in Court", *The Diplomat*, 17 February 2022, see https://thediplomat.com/2022/02/fukushima-disasters-impact-on-health-will-be-challenged-in-court/, accessed 17 June 2022.

612 - Sakura Murakam, "Japan's top court orders damages for Fukushima victims in landmark decision-NHK", *Reuters*, 4 March 2022, see https://www.reuters.com/world/asia-pacific/japans-top-court-orders-damages-fukushima-victims-landmark-decision-nhk-2022-03-04/, accessed 17 June 2022.

613 - *Kyodo News*, "Japan's top court rules state not liable for Fukushima disaster", 17 June 2022, see https://english.kyodonews.net/news/2022/06/e3802f4efbc6-breaking-news-japans-top-court-rules-state-not-liable-for-fukushima-disaster.html, accessed 17 June 2022.

614 - *Kyodo News*, "Court orders TEPCO to pay 73.5 million yen over Fukushima crisis", 2 June 2022, see https://english.kyodonews.net/news/2022/06/2ece2b577eea-court-orders-tepco-compensation-over-fukushima-crisis.html, accessed 17 June 2022.

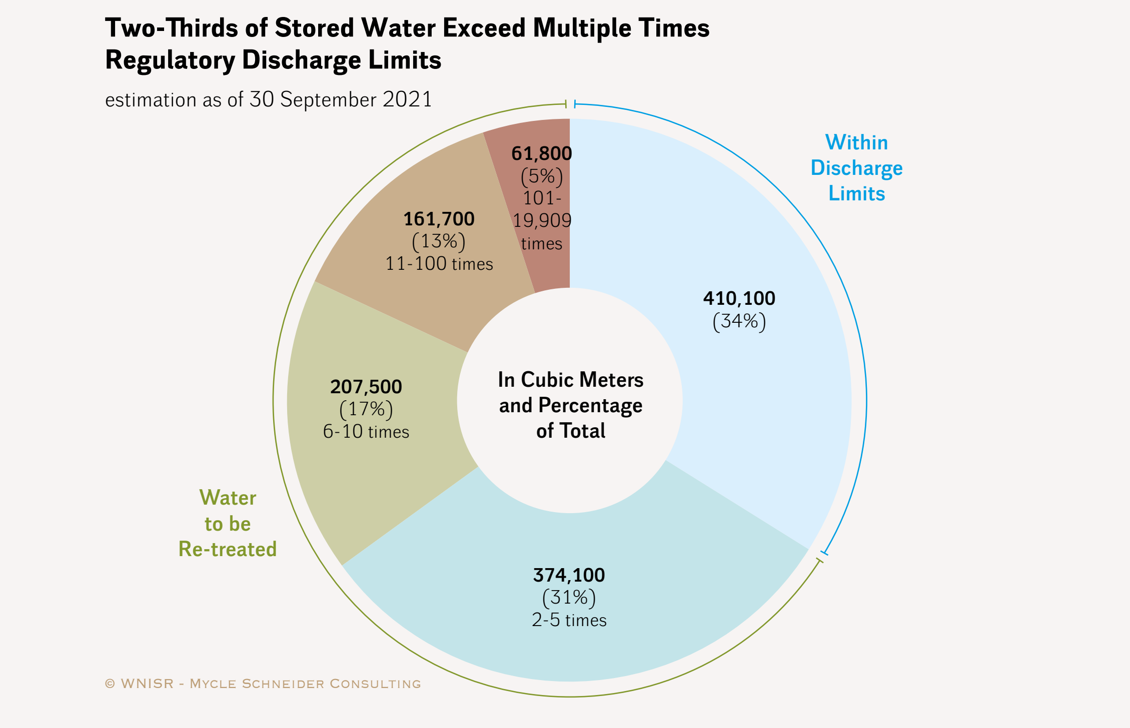
four have appealed the court ruling.[615] The criminal case against three of these four former executives had resulted in their acquittal in 2019.[616]

Conclusion

Eleven years have passed since the Fukushima nuclear disaster began. Although there has been some steady progress in decommissioning and food safety, many onsite and offsite challenges remain.

Onsite, little progress was made in removing the remaining spent fuel from cooling pools and in the investigation of debris removal options. Public trust in TEPCO and the government has not been restored and has been further stressed considering the difficulties with water treatment.

Figure 43 · Two-Thirds of Stored Water Exceed Contamination Limits for Discharge Multiple Times



Sources: TEPCO Holdings, "Treated Water Portal Site", September 2021.[617]

Note: This chart shows that two thirds of ALPS-treated water require a second or additional treatments to make sure that all radionuclide concentrations remain below regulatory limits, as current contamination levels exceed limits by several to up to almost 20,000 times.

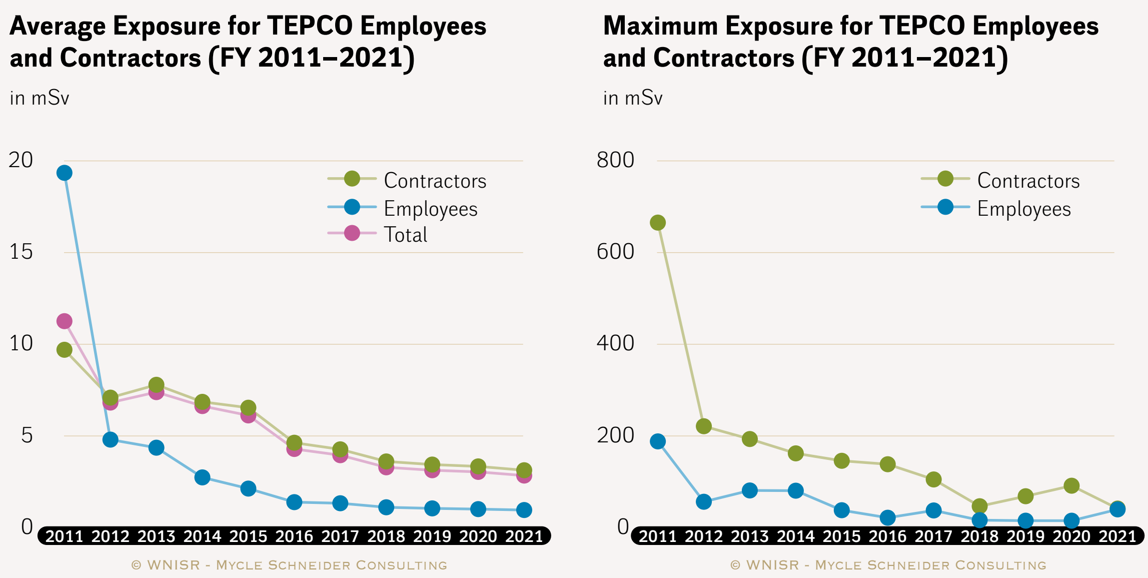
615 - *The Mainichi*, "Ex-TEPCO execs appeal $95 bil. damages ruling over Fukushima crisis", 27 July 2022, see https://mainichi.jp/english/articles/20220727/p2g/00m/0na/053000c, accessed 15 September 2022.

616 - *Reuters*, "Tokyo court orders ex-Tepco execs to pay $95 bln damages over Fukushima disaster", 13 July 2022, see https://www.reuters.com/business/environment/tokyo-court-orders-ex-tepco-execs-pay-95-bln-damages-over-fukushima-disaster-nhk-2022-07-13/, accessed 15 July 2022.

617 - TEPCO Holdings, "Treated Water Portal Site", as of 9 June 2022, see https://www.tepco.co.jp/en/decommission/progress/watertreatment/oceanrelease/index-e.html, accessed 14 June 2022.

Offsite, according to sample measuring results, food contamination has been significantly reduced and the number of countries banning the import of Japanese food has also declined. And for the first time, the evacuation order was lifted for a part of the area designated as "difficult-to-return". Only a fraction of the residents has returned, and the management of contaminated soil will likely take a long time. Finally, legal fights over the compensation of victims continue. In short, the Fukushima disaster is still underway.

Figure 44 · Exposure for TEPCO Employees and Contractors (FY 2011–2021)



Source: TEPCO, 2022[618]

618 - TEPCO Holdings, "Evaluation of the exposure dose of workers engaged in radiation work at the Fukushima Daiichi Nuclear Power Station", 28 April 2022.

DECOMMISSIONING STATUS REPORT 2022

INTRODUCTION

At the end of 2021, the number of closed power reactors exceeded 200 for the first time. Decommissioning nuclear power plants is an important element of the nuclear power system. Defueling, deconstruction, and dismantling—summarized by the term decommissioning—are the final steps in the lifetime 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, execution, and financing. Decommissioning was rarely considered in the reactor design, and the costs for decommissioning at the end of the lifetime of a reactor were usually expected to be discounted away, and thus, subsequently, largely ignored. However, as an increasing 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 of said process. 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. An indicator for the progress of this stage is the defueling of the reactor, as it is crucial for further undertakings: defueling 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) as well as the biological shield.
- The **ease-off stage** comprises the removal of operating systems as well as the decontamination of onsite 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. Some countries also permit the release as a brownfield site, which means that the buildings can also be further used, for nuclear or other, mostly industrial purposes.

This technical procedure can begin after varying amounts of time after reactor shutdown. This depends on the strategy the operator chooses. These include:

- **immediate dismantling**, that is characterized by a rapid beginning of decommissioning activities after 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 become permanent.

One of these strategies or a mix of them have been adopted by most countries, although some have placed restrictions, such as France or Germany.[619]

With respect to financing, four main approaches are observable: Public budget, external segregated fund, internal non-segregated fund, and internal segregated fund (for more details, see WNISR2018).

GLOBAL OVERVIEW

Decommissioning Worldwide

As of 1 July 2022, worldwide a total of 204 reactors, corresponding to 97.4 GW of capacity, have been closed. Since WNISR2021, eight additional reactors (6.1 GW) have been closed: two in the U.K., three in Germany and one each in Russia, Pakistan and the U.S.

Of the total number of closed units, 123 (60 percent) are located in Europe (98 in Western Europe and 25 in Central and Eastern Europe), followed by nearly a quarter of the total in North America (47) and one sixth in Asia (34).

Almost four in five or 160 reactors used three technologies:

- Pressurized Water Reactors (PWRs) with 64 units or 31 percent,
- Boiling Water Reactors (BWRs) with 54 units or 26 percent, and
- Gas-Cooled Reactors (GCRs) with 42 units or 21 percent, of which the majority (31 units) are located in the U.K.

Table 10 provides an overview of the closed reactors worldwide. Compared to WNISR2021, the table also includes the number of defueled reactors, and those that have been released from regulatory supervision, i.e. where a full greenfield situation has been re-established.

619 - Tim Scherwath, Ben Wealer and Roman Mendelevitch, "Nuclear decommissioning after the German Nuclear Phase-Out an integrated view on new regulations and nuclear logistics", German Institute for Economic Research, *Energy Policy*, Vol. 137, February 2020; 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", U.S. Nuclear Regulatory Commission, February 2022, see https://www.nrc.gov/docs/ML2134/ML21347A080.pdf, accessed 4 July 2022.

Table 10 - Overview of Reactor Decommissioning Worldwide (as of July 2022)

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.	41	1	7 (7)	3	1	12	17 (6)	41% (15%)
U.K.	34	4	13 (11)	9	0	8	0	0%
Germany	33	2	8 (5)	9	9	1	4 (3)[b]	12% (9%)
Japan	27	0	26 (4)	0	0	0	1 (1)	4% (4%)
France	14	0	4 (1)	2	0	8	0	0%
Russia	10	1	0	0	0	9	0	0%
Sweden	7	0	3 (1)	4	0	0	0	0%
Canada	6	0	0	0	0	6[c]	0	0%
Bulgaria	4	0	4	0	0	0	0	0%
Italy	4	0	3 (2)	1	0	0	0	0%
Ukraine	4	0	0	0	0	4[d]	0	0%
Slovakia	3	0	1 (1)	2	0	0	0	0%
Spain	3	0	1	0	1	1	0	0%
Taiwan	3	1	2	0	0	0	0	0%
Lithuania	2	0	2 (2)	0	0	0	0	0%
South Korea	2	0	2	0	0	0	0	0%
Armenia	1	0	0	0	0	1[e]	0	0%
Belgium	1	0	0	0	1	0	0	0%
India	1	0	1 (1)	0	0	0	0	0%
Kazakhstan	1	0	0	0	0	1	0	0%
Netherlands	1	0	0	0	0	1	0	0%
Pakistan	1	1	0	0	0	0	0	0%
Switzerland	1	0	1	0	0	0	0	0%
Total	**204**	**10**	**78 (35)**	**30**	**12**	**52**	**22 (10)**	**11% (5%)**

Sources: Various, compiled by WNISR, 2022

Notes:

(a) - Many recently closed reactors have not officially begun with decommissioning and are in a so-called "post-operational stage". These are Brokdorf and Grohnde in Germany, Kursk-1 in Russia, Kuosheng-1 in Taiwan, Dungeness B-1 & -2 and Hunterston B-1 & -2 in the U.K. and Palisades in the US.

(b) - Contrary to the categorization in previous WNISR editions that counted Gundremmingen-A to be fully decommissioned, the plant should rather be placed into the "Ease-Off-Stage" of decommissioning, as work is still ongoing.

(c) - Contrary to categorization in previous WNISR editions, the Douglas Point only reached the warm-up stage in August 2022, thus as of July 2022, Canada does not count any reactor beyond LTE.

(d) - With the "New Safe Confinement" being completed at Chernobyl-4, this reactor is now categorized as LTE.

(e) – Contrary to previous WNISR editions, the Armenia/Metsamor-1 reactor is categorized as LTE.

Decommissioning plays an increasing role in nuclear politics, both in timing and the production process, as well as the financing thereof. The numbers of reactors in active decommissioning will increase significantly: not taking into account the 110 reactors which started operating before 1982, assuming a 40-year average lifetime, a further 158 reactors will close by 2030 (reactors connected to the grid between 1982 and 1990); and an additional 143 will be closed by

2062. This does not even account for an additional 29 reactors in Long-term Outage (LTO) and 53 reactors under construction as of mid-2022.

Overview of Reactors with Completed Decommissioning

As of mid-2022, 182 units are globally awaiting or in various stages of decommissioning, five more than one year earlier (Gundremmingen-A in Germany was previously incorrectly considered as fully decommissioned).

Since WNISR2021, three reactors—all in the U.S.—have completed the technical decommissioning process. As WNISR2022 has corrected the status of one German reactor from "completed" to "ease off", the number of completed units totals 22.

Humboldt Bay, a small BWR with 63 MWe capacity, located in California and closed in 1976, was declared fully decommissioned in late 2021.[620] The site has not yet been released from full regulatory control, as spent fuel is still located in an on-site interim storage facility.[621] The two 1040 MWe PWRs at Zion, Illinois, are awaiting final approval of their license termination applications by the U.S.NRC.[622] Technical decommissioning work was completed at both units in 2020.[623]

Of the 22 decommissioned reactors, only 10 have been returned to greenfield sites. The average duration of the decommissioning process, independent of the chosen strategy, is around 21 years, with a very high variance: the minimum of six years for the 22-MW Elk River plant, and the maximum of 45 years for the 63-MW reactor at Humboldt Bay, both in the U.S.

Only three countries amongst the 23 with closed nuclear 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 U.S. reactors are amongst the most rapidly decommissioned. 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. Würgassen has de facto completed the technical decommissioning process but, legally, cannot be released from regulatory control as buildings are used for interim storage of wastes.[624] Gundremmingen-A, erroneously classified as fully decommissioned in previous WNISR editions, has in fact not yet completed the process as demolition work is still ongoing and expected to be finalized only in the early 2030s.[625] In Japan, the only reactor decommissioned

620 - Radwaste Solutions, "Humboldt Bay official decommissioned, site released for unrestricted use", *Nuclear Newswire*, November 2021, see https://www.ans.org/news/article-3456/humboldt-bay-officially-decommissioned-site-released-for-unrestricted-use/, accessed 9 June 2022.

621 - A Snyder, G. Chapman and K. Pinkston, "Safety Evaluation Report Related to the Termination of Facility Operating Licence No. DPR-7 (Humboldt Bay Power Plant, Unit 3)", Docket No. 50-133, United States Nuclear Regulatory Commission, November 2021, see https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML21295A251, accessed 9 June 2022.

622 - *NEI Magazine*, "US NRC delays release of La Crosse and Zion sites for unrestricted use", 20 September 2021, see https://www.neimagazine.com/news/newsus-nrc-delays-release-of-la-crosse-and-zion-sites-for-unrestricted-use-9095573/, accessed 9 June 2022.

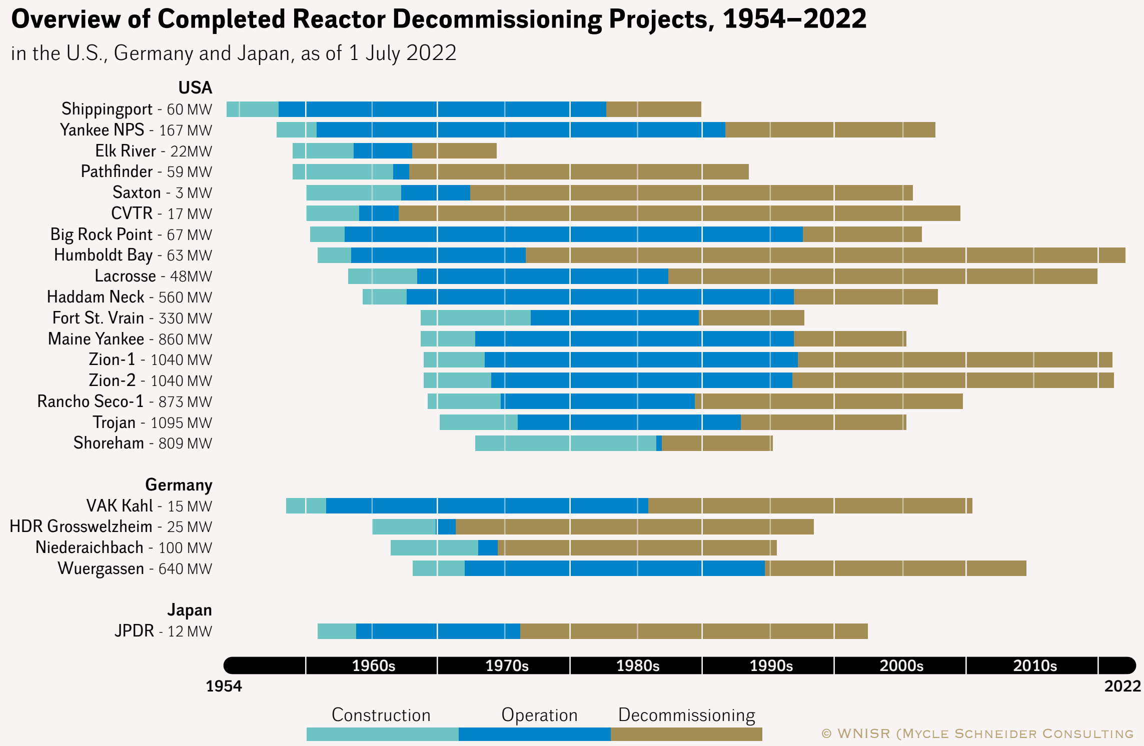
623 - U.S.NRC, "Zion Units 1 & 2", United States Nuclear Regulatory Commission, Updated April 2022, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/zion-nuclear-power-station-units-1-2.html, accessed 9 June 2022.

624 - Ines Bredberg, Johann Hutter et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2018" ["Status Report on Nuclear Energy Use in the Federal Republic of Germany 2018"], Abteilung Kerntechnische Sicherheit und atomrechtliche Aufsicht in der Entsorgung, Bundesamt für kerntechnische Entsorgungssicherheit, Federal Office for Nuclear Disposal, August 2019.

625 - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes—Rückbau von Kernkraftwerken" [Report pursuant to §7 of the Transparency Act—Decommissioning of Nuclear Power Plants"], Deutscher Bundestag, 20. Wahlperiode, 2021.

was a small 10 MW demonstration plant, whereas none of the large commercial reactors has yet been decommissioned.[626] Figure 45 provides the timelines of the 22 reactors that have completed the decommissioning process.[627]

Figure 45 · Overview of Completed Reactor Decommissioning Projects, 1954–2022



Sources: Various, compiled by WNISR, 2022

Note:

Contrary to the categorization in previous WNISR editions that counted Gundremmingen-A to be fully decommissioned, the plant should rather be placed into the "Ease-Off-Stage" of decommissioning, as work is still ongoing.

Overview of Ongoing Reactor Decommissioning

This section contains a brief overview of the decommissioning status in the countries that are not covered in the subsequent case studies.

Following a partnership agreement with the European Union, the **Armenian** Medzamor (or Metsamor) nuclear power plant is to be completely closed as soon as possible due to significant safety concerns.[628] Unit 1 was already closed in 1989 after an earthquake.

626 - Marc Schmittem, "Nuclear Decommissioning in Japan—Opportunities for European Companies", EU-Japan Centre for Industrial Cooperation, March 2016, see https://www.eu-japan.eu/sites/default/files/publications/docs/2016-03-nuclear-decommissioning-japanschmittem-min_0.pdf, accessed 23 April 2018.

627 - The Decommissioning Report does not cover all smaller research reactors that may have been shut down in some countries.

628 - 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://www.eeas.europa.eu/sites/default/files/armenia_partnership_implementation_report_2020.pdf, accessed 8 June 2022.

A pilot decommissioning project by Rosatom subsidiary Nukem Technologies, EWN and WorleyParsons is currently underway.[629] Unit 2 is scheduled to operate until September 2026.[630]

In **Belgium**, the only reactor currently undergoing decommissioning is the prototype 10 MW reactor BR-3 in Mol. The reactor, closed in 1987, has recently entered the ease-off stage and is used as a lead-and-learn site for future decommissioning projects.[631] Currently, the Belgian legislation calls for the closure of all seven operational reactors at Doel and Tihange until the end of 2025 and estimated decommissioning costs of €18 billion (US$18.82 billion).[632] In March 2022, however, the Belgian administration decided to initiate negotiations with the operator to extend operational lifetimes of Tihange-3 and Doel-4 until 2035 (see section on Belgium).[633]

Four PWR-type reactors of the VVER V-230 design are currently undergoing decommissioning in **Bulgaria** (Kozloduy 1–4). At all four units of Kozloduy nuclear plant, turbine hall dismantling was completed in 2019.[634] Since then, not much progress has been made. Preparations and detailed plans for reactor dismantling are to begin in 2022.[635]

Rajasthan-1 in **India**—placed in LTO status since 2004 and since 2014 considered as closed by WNISR—has been completely defueled and is currently "maintained under dry preservation".[636] WNISR considers the reactor in the warm-up-phase.

Decommissioning has been underway since 1998 at Aktau BN-350,[637] a sodium-cooled fast reactor in **Kazakhstan**. The reactor is being prepared for LTE, expected to last for 50 years.[638]

629 - Nukem Technologies, "Pilot Decommissioning Project at Metsamor Nuclear Power Plant", Undated, see https://www.nukemtechnologies.de/en/projects/am/pilot-decommissioning-project-at-metsamor-nuclear-power-plant, accessed 8 June 2022.

630 - *WNN*, "Long-term safety of Armenian plant reviewed by IAEA", 8 November 2021, see https://www.world-nuclear-news.org/Articles/Long-term-safety-of-Armenian-plant-reviewed-by-IAE, accessed 8 June 2022.

631 - Wouter Broeckx, Sven Boden et al., "Decommissioning of the BR3 biological shield: How a proper data analysis facilitates the D&D process", in proceedings of "International Conference on Decommissioning Challenges: Industrial Reality, Lessons learned and Prospects (DEM 2021)", 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.

632 - Andreas Kockartz, "Der Rückbau der belgischen Kernkraftwerke kostet mindestens 18 Mia. €" ["Decommissioning of Belgian Nuclear Power Plants To Cost at Least €18 Bn], *Belga*, as published on *vrtNWS* (in German), 30 June 2021, see https://www.vrt.be/vrtnws/de/2021/06/30/der-rueckbau-der-belgischen-kernkraftwerke-kostet-mindestens-18/, accessed 10 June 2022.

633 - *RTBF*, "Prolongation du nucléaire : le conseil des ministres avalise la prolongation de deux réacteurs au-delà de 2025" ["Lifetime Extension of Nuclear Power: the Council of Ministers approves the extension of Two Reactors Beyond 2025"], 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 21 June 2022.

634 - SERAW, "Decommissioning of nuclear installations", State Enterprise Radioactive Waste, 2022, see https://tinyurl.com/DPRAODecom, accessed 8 June 2022.

635 - European Commission, "Annex 3—Decommissioning programme" in "Nuclear Decommissioning Assistance Programme—Kozlduy Programme—Work Programme 2021-2022", 2021, see https://energy.ec.europa.eu/system/files/2022-01/C_2021_8857_F1_ANNEX3_EN_V1_P1_1606149.PDF, accessed 8 June 2022.

636 - Nuclear Power Corporation of India Ltd, "Rawatbhata Rajasthan Site", Department of Atomic Energy, Undated, see https://www.npcil.nic.in/content/501_1_rawatbhatarajasthansite.aspx, accessed 9 June 2022.

637 - The reactor was considered in operation until April 1999, although it had not produced electricity since 1988.

638 - Kamen Kraev, "Kazakhstan / 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 9 September 2022.

In the **Netherlands**, the 55 MW reactor Dodewaard was placed in LTE for forty years in 2005 with the aim to return the site to a greenfield status.[639]

In August 2021, **Pakistan** closed its first reactor KANUPP-1, a 90-MW CANDU reactor that had been operational for 50 years.[640] No indication of a decommissioning strategy has been communicated.

Slovakia's decommissioning efforts are advancing, with reactor pressure vessels having been removed in late 2021 at Bohunice-1 and -2, two PWR-type VVER V230 design reactors also jointly called Bohunice V1), by Slovakian company JAVYS and a Westinghouse-led consortium.[641] Completion of Bohunice A1 decommissioning, a 93-MW heavy water GCR-type reactor, is scheduled for 2033.[642]

Sweden's latest reactor closures at Ringhals nuclear power plant occurred in 2020. Both reactors at the site are currently in the warm-up stage. Actual decommissioning work is set to begin in the third quarter of 2022 and to be conducted by Westinghouse.[643] The first Swedish reactor, Ågesta, was closed in 1974 and subsequently defueled.[644] The plant was used as a training facility until 2020, when Westinghouse was tasked with its dismantling.[645] Reactors at Barsebäck and Oskarshamn are currently in the "hot-zone". At Barsebäck-1, the reactor pressure vessel was successfully dismantled in late 2021.[646] At Barsebäck-2 the vessel was dismantled by Westinghouse in 2018.[647] Reactor internals at Oskarshamn were dismantled for both reactors in 2019 by GE Hitachi Nuclear Energy.[648] Decommissioning work is scheduled to be completed by 2028 at both nuclear power plants.[649]

639 - 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.

640 - PAEC, "Nuclear Power: A Viable Option for Electricity Generation", Pakistan Atomic Energy Commission, Undated, see https://paec.gov.pk/nuclearpower/, accessed 8 June 2022.

641 - *WNN*, "Pressure Vessel Segmented at Bohunice", 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.

642 - Javys, "Annual Report 2020", 2021, see https://www.javys.sk/data/web/dokumenty/vyrocne-spravy/vs-en-javys-2020-fin.pdf, accessed 8 June 2022.

643 - Vattenfall, "Annual and Sustainability Report 2021— Fossil-free living within one generation", 2021, see https://mb.cision.com/Main/865/3534511/1555469.pdf; and *WNN*, "Ringhals reactors to be dismantled by Westinghouse", August 2019, see https://www.world-nuclear-news.org/Articles/Ringhals-reactors-to-be-dismantled-by-Westinghouse, both accessed 8 June 2022.

644 - Vattenfall, "Ågesta power plant", Undated, see https://history.vattenfall.com/stories/agesta-power-plant, accessed 8 June 2022.

645 - Westinghouse Electric Company, "Westinghouse Wins Environmental Contract with Vattenfall to Dismantle Ågesta Nuclear Plant", 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.

646 - *WNN*, "Uniper completes dismantling of two RPVs in parallel", 23 March 2022, see https://www.world-nuclear-news.org/Articles/Uniper-completes-dismantling-of-two-RPVs-in-parall, accessed 8 June 2020.

647 - *NEI Magazine*, "Decommissioning progress at Sweden's Barsebäck", 19 March 2018, see https://www.neimagazine.com/news/newsdecommissioning-progress-at-swedens-barsebck-6087602, accessed 8 June 2020.

648 - *WNN*, "Dismantling of Oskarshamn Reactor Internals Completed", 19 December 2019, see https://world-nuclear-news.org/Articles/Dismantling-of-Oskarshamn-reactor-internals-comple, accessed 8 June 2022.

649 - Kristina Gillin, "Sweden Prepares For a Decade of Nuclear Decommissioning", *NS Energy*, 27 February 2020, see https://www.nsenergybusiness.com/news/nuclear-decommissioning-sweden/, accessed 23 August 2022.

Switzerland has limited decommissioning experience, having completed technical decommissioning at the research reactor Lucens in 2004.[650] Decommissioning of the commercial reactor at Mühleberg began shortly after its closure in 2019. Hot-zone works are expected to last from 2025 to 2030 and plans indicate decommissioning to be completed in 2034.[651]

In **Taiwan**, nuclear reactors are being progressively closed with Kuosheng-1 being the latest closure in 2021.[652] Mid-2021, operator Taipower submitted the application to cease operation at the Maanshan nuclear power plant by 2025.[653] Decommissioning of all Taiwanese reactors (including still operational reactors) is to be completed by 2043,[654] but at Chinshan-1 (closed in 2014) delays occurred already in 2018 due to belated approval of onsite dry storage facilities.[655] No further information on the potential revision of the decommissioning plans at Chinshan-1 and -2 has been published.[656] Taipower considers that decommissioning procedures last 25 years upon issuance of the decommissioning permit, which the Atomic Energy Commission granted on 12 July 2019. Taipower announced it had initiated decommissioning work when the license became effective on 16 July 2019.[657]

In **Ukraine**, work at the four reactors of the Chernobyl plant is continuing. Chernobyl 1–3 are currently being defueled[658] and will be placed into LTE following the chosen deferred dismantling strategy.[659] The New Safe Confinement for Unit 4 was completed in 2016.[660]

650 - ENSI, "Serie Lucens: Der Rückbau eines Pionierwerks" ["Lucens Series: The Dismantling of a Pioneering Plant"], Eidgenössisches Nuklearsicherheitsinspektorat, Swiss Federal Nuclear Safety Inspectorate, 14 June 2012, see https://www.ensi.ch/de/2012/06/14/serie-lucens-der-rueckbau-eines-pionierwerks/, accessed 8 June 2022.

651 - BKW, "Stilllegung Kernkraftwerk Mühleberg" ["Decommissioning of Nuclear Power Plant Mühleberg"], August 2020, see https://www.bkw.ch/fileadmin/user_upload/03_Energie/03_05_Energieproduktion/Stilllegung_Kernkraftwerk_Muehleberg/Kompetenzbroschuere_Stilllegung_KKM_DE.pdf, accessed 8 June 2022.

652 - *WNN*, "Early shutdown for Taiwanese reactor", 1 July 2021, see https://www.world-nuclear-news.org/Articles/Early-shutdown-for-Taiwanese-reactor, accessed 9 June 2022.

653 - *WNN*, "Taipower applies to decommission Maanshan plant", 27 July 2021, see https://www.world-nuclear-news.org/Articles/Taipower-applies-to-decommission-Maanshan-plant, accessed 9 June 2022.

654 - *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.

655 - *EFE:*, "Taiwan delays decommissioning of first nuclear reactor", *Agencia EFE*, December 2018, see https://www.efe.com/efe/english/world/taiwan-delays-decommissioning-of-first-nuclear-reactor/50000262-3832747, accessed 9 June 2022.

656 - AEC, "Annual Report 2020", Atomic Energy Council, June 2021, see https://www.aec.gov.tw/share/file/e_law/HWyB-yAoTUj3MeqQePVlFw__.pdf, accessed 9 June 2022.

657 - Taipower, "First Nuclear Power Plant Decommissioning Plan", Undated, see https://www.taipower.com.tw/en/page.aspx?mid=4506, accessed 8 September 2022.

658 - 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.

659 - *Power Technology*, "Chernobyl Nuclear Power Plant Decommissioning, Ukraine", 1 March 2022, see https://www.power-technology.com/projects/chernobyl/, accessed 9 June 2022.

660 - 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.

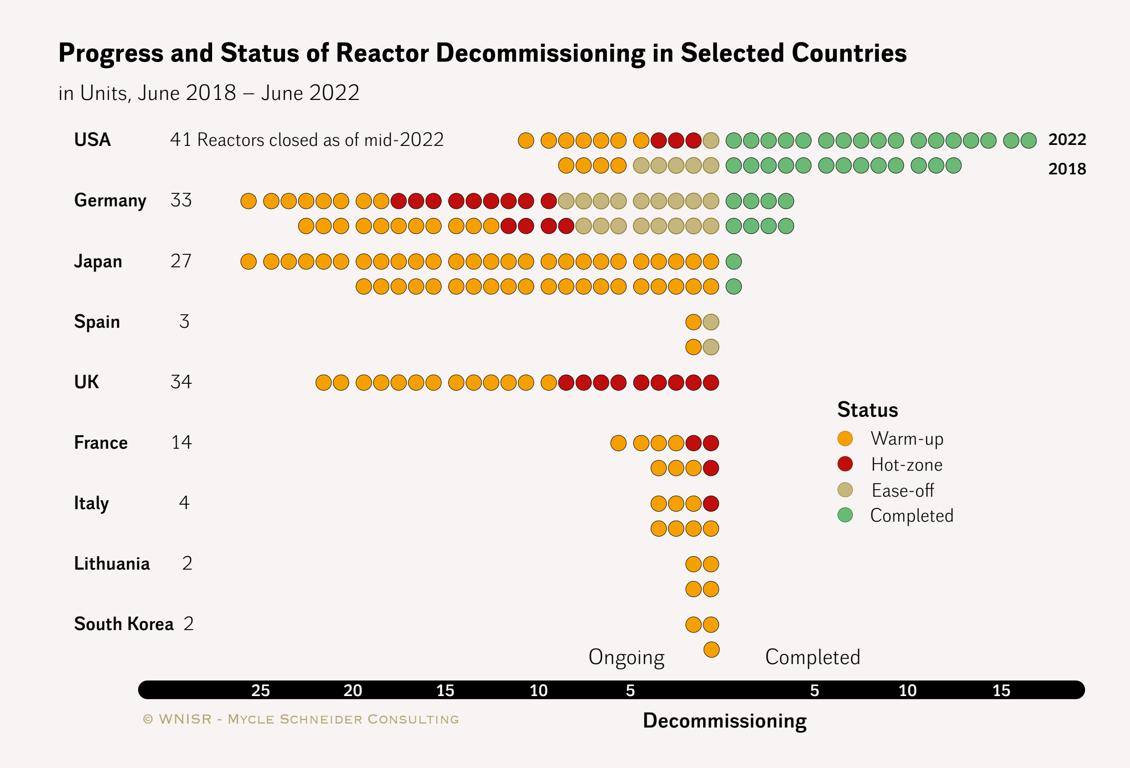
COUNTRY CASE STUDIES

Decommissioning in selected countries

This section provides an update of decommissioning development reviews in eleven major countries: the U.S., Germany, Japan, Spain, the U.K., France, Italy, Lithuania, South Korea, Canada, and Russia. As in previous years, decommissioning projects encounter delays as well as cost increases. This section provides information on developments since WNISR2021. WNISR2022 counted 146 reactors currently in the different decommissioning stages (or in LTE) in these 11 countries; this represents around 85 percent of all closed reactors. Of these, 66 are currently in the "warm-up stage", 24 reactors in the "hot-zone -stage", and 11 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 52 reactors in LTE worldwide, 45 located in the 11 countries.

Figure 46 · Progress and Status of Reactor Decommissioning in selected countries



Sources: Various, compiled by WNISR, 2022

Notes:

After a decommissioning strategy change, the U.K. has begun to move reactors from LTE to various stages of decommissioning. This figure does not include Canada and Russia, with no reactors beyond LTE.

Contrary to the categorization in previous WNISR editions that counted Gundremmingen-A to be fully decommissioned, the plant should rather be placed into the "Ease-Off-Stage" of decommissioning, as work is still ongoing.

Figure 46 reflects the slow progress that the global decommissioning industry is making. Over the past four years, few reactors have moved on in their decommissioning processes. Most notably, the U.K. has changed its initial LTE approach for its GCR Magnox fleet to a more short-term dismantling approach. Germany is also making progress, with the last three still operational reactors scheduled to close by the end of 2022. In the U.S., work in the hot-zone began at four reactors. For further details, see the following Case Studies.

United States

The U.S. has not only the largest fleet of operating (92) and closed reactors but also the highest number of decommissioned units representing nearly three quarters of the global total.

In the U.S., as of mid-2022, 41 reactors (20 GW) have been closed.[661] By 2050, at least 100 reactors are likely to undergo decommissioning. Of the 41 closed reactors (21 PWR, 14 BWR, 2 HTGR, 1 FBR, 1 PHWR, 2 others)[662], 17 or 7.1 GW have been decommissioned. Currently, decommissioning work is ongoing at 11 units:

- Seven reactors are in the warm-up stage: Crystal River-3, Indian Point-2 &-3, Kewaunee, San Onofre-2 & -3 and Vermont Yankee;
- Three reactors are in the hot-zone stage: Fort Calhoun-1, Oyster Creek and Pilgrim-1;
- One reactor is in ease-off stage: San Onofre-1.

Since mid-2021, some progress was made in the U.S. where one additional reactor was closed. Most notably, three reactors completed their technical decommissioning. Humboldt Bay was fully decommissioned in 2021, and all land—except for the on-site interim spent-fuel storage-facility—has been released for unrestricted use.[663]

Zion-1 and -2 (work completed in 2020) are however still awaiting delicensing decisions by the NRC for unrestricted use (as is LaCrosse).[664]

Furthermore, three reactors have moved into the hot-zone-stage.

At Fort Calhoun, initial plans were changed from deferred to direct dismantling, with the aim of completing the task by 2026.[665] As of February 2022, reactor pressure vessel segmentation was underway.[666]

661 - 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, see https://www.nrc.gov/docs/ML1825/ML18257A301.pdf, accessed 8 August 2022.

662 - PWR: Pressurized Water Reactor; BWR: Boiling Water Reactor; HTGR: High-Temperature Gas-Cooled Reactor; FBR: Fast Breeder Reactor; PHWR: Pressurized Heavy-Water Reactor.

663 - U.S. NRC, "Safety Evaluation Report Related to the Termination of Facility Operating Licence No. DPR-7 (Humboldt Bay Power Plant, Unit 3)", Docket No. 50-133, November 2021, op. cit.

664 - *NEI Magazine*, "US NRC Delays Release of La Crosse and Zion Sites for Unrestricted Use", 20 September 2021, op. cit.

665 - U.S.NRC, "Fort Calhoun Station", United States Nuclear Regulatory Commission, Updated 7 April 2022, see https://www.nrc.gov/info-finder/reactors/fcs.html, accessed 9 June 2022.

666 - Jason Kuiper, "Work continues at Fort Calhoun Station", *The Wire*, 1 February 2022, see https://oppdthewire.com/work-continues-at-fort-calhoun-station/, accessed 9 June 2022.

Prior to the acquisition of Oyster Creek by Holtec, Exelon had opted for a strategy involving LTE.[667] In 2018, Holtec decided to directly dismantle the site,[668] and was able to defuel the plant in 32 months.[669] In parallel, several components have been demolished, such as the air ejection off-gas building or the torus water storage tank.[670]

Pilgrim-1 was defueled in late 2021 and work has since begun to dismantle the reactor itself.[671] The plant is to be fully decommissioned by 2027 and is also operated by Holtec.[672]

In April 2022, the NRC approved the license transfer at Kewaunee reactor from Dominion Nuclear Projects to EnergySolutions. The transfer had been requested in May 2021 after the dry storage facility had already been transferred to EnergySolutions in 2018. Consequently, active decontamination and demolition work is expected to begin in 2022 and be completed by 2030.[673]

The early shutdown of Palisades marks the latest reactor closure in the US. The plant was originally licensed to operate until 2031 but was taken off the grid in May 2022.[674] In June 2022, Holtec became the owner of the plant and plans to complete decommissioning by 2041.[675]

For the time being, decommissioning remains the responsibility of the operators, who tender out to specialized companies some of the work, especially in the hot-zone stage.[676] It seems, however, that the new organizational model of selling the license to a decommissioning contractor (identified in WNISR2018) is 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 to reap efficiency gains through the co-management of the decommissioning process by a company owning disposal facilities.

667 - Holtec Decommissioning International, "Notification of Revised Post-Shutdown Decommissioning Activities Report and Revised Site-Specific Decommissioning Cost Estimate for Oyster Creek Nuclear Generating Station", submitted to U.S. NRC, 28 September 2018, see https://holtecinternational.com/wp-content/uploads/2021/02/HDI-PSDAR-DCE-ML18275A116.pdf, accessed 9 June 2022.

668 - Ibidem.

669 - *WNN*, "Oyster Creek defuelled in record time", 24 May 2021, see https://www.world-nuclear-news.org/Articles/Oyster-Creek-defuelled-in-record-time, accessed 9 June 2022.

670 - *WNN*, "Decommissioning progresses apace at Oyster Creek and Pilgrim", 26 August 2021, see https://www.world-nuclear-news.org/Articles/Decommissioning-progresses-apace-at-Oyster-Creek-a, accessed 9 June 2022.

671 - Paul Miller, "Accelerated Decommissioning of Pilgrim Nuclear Power Station: A Progress Report", *Power Mag*, March 2022, see https://www.powermag.com/accelerated-decommissioning-of-pilgrim-nuclear-power-station-a-progress-report/, accessed 9 June 2022.

672 - *NS Energy*, "Pilgrim Nuclear Power Plant Decommissioning", 2022, see https://www.nsenergybusiness.com/projects/pilgrim-nuclear-power-plant-decommissioning/, accessed 9 June 2022.

673 - *NEI Magazine*, "US NRC approves Kewaunee NPP licence transfer", 4 April 2022, see https://www.neimagazine.com/news/newsus-nrc-approves-kewaunee-npp-licence-transfer-9599399/, accessed 9 June 2022.

674 - entergy, "Palisades Power Plant", Updated in 2022, see https://www.entergy-nuclear.com/nuclear-sites/palisades/, accessed 16 June 2022.

675 - *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; and *WNN*, "Palisades sale from Entergy to Holtec completed", 29 June 2022, see https://www.world-nuclear-news.org/Articles/Palisades-sale-from-Entergy-to-Holtec-completed, accessed 4 July 2022.

676 - Conrad Cooke and Holger Spann, "Reactor vessel internals segmentation at Zion", *NEI Magazine*, 20 September 2013, see http://www.neimagazine.com/features/featurereactor-vessel-internals-segmentation-at-zion/; and AREVA, "Decommissioning & Dismantling", Undated, see http://us.areva.com/EN/home-3783/orano-usa-decommissioning--dismantling.html; all accessed July 2022.

However, it is unclear whether this organizational model will resolve the financing issue or end up in the socialization of costs in the end.[677]

Germany

By the end of 2021, Germany had a total of 33 closed reactors the second largest closed fleet worldwide. It also has the second highest number of decommissioned units. The latest closures were Brokdorf, Grohnde (both operated by Preussen Elektra) and Gundremmingen-C (operated by RWE) on 31 December 2021 after an average time of operation of 36 years.

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 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 reactor THTR-300 is the only German reactor still in LTE. Recently closed plants Grohnde and Brokdorf are still awaiting approval of their decommissioning applications and are thus not yet placed into any stage. (See WNISR2021 for further details on German nuclear decommissioning procedure.)

Currently, two reactors are in post-operational stage and one in LTE, while decommissioning work is being conducted at 26 reactors:

- Eight reactors are in the warm-up-stage: Biblis-A & -B (both defueled), Grafenrheinfeld (defueled), Gundremmingen-B & -C, Krümmel (defueled), Lingen (defueled) and Philippsburg-2;
- Nine reactors are in the hot-zone-stage: AVR Jülich, Brunsbüttel, Isar-1, 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.

Decommissioning has been underway at Gundremmingen since 1983. This nuclear power plant consists of two parts, with KRB A or Gundremmingen-A, a BWR that was closed in 1977, and KRB II, incorporating Gundremmingen-B and -C, two BWRs commissioned in 1984 and 1985, respectively.

Contrary to the categorization in previous WNISR editions that counted Gundremmingen-A to be fully decommissioned, the plant should rather be placed into the "Ease-Off-Stage" of decommissioning, as work is still ongoing. The site has been free of fuel since 1988 and most critical components have successfully been dismantled. In 2020, demolition at the reactor building continued and is expected to be completed sometime in the early 2030s. Individual buildings of the Gundremmingen-A site have been reassigned to KRB II and are currently being used as a facility for dismantling and decontamination of components from KRB II. Furthermore, the site includes an interim storage facility that is managed by BGZ

677 - Rebecca Lordan-Perret, Robert D. Sloan and Robert Rosner, "Decommissioning the U.S. nuclear fleet: Financial assurance, corporate structures, and bankruptcy", *Energy Policy*, July 2021.

(Gesellschaft für Zwischenlagerung mbH), the German state-run company for long-term waste management. A decommissioning license for Gundremmingen-B and -C was granted in May 2021. With Gundremmingen-C only closed in December 2021, decommissioning work is expected to continue into the 2040s.[678]

The Krümmel reactor was shut down in 2011. In 2015, the operator applied to the local authority in the state of Schleswig-Holstein to fully shutdown and decommission the plant. However, the permit has not yet been granted. During the application process, the operator planned to defuel the plant, which was achieved in late 2019. Whether the plan to decommission Krümmel by 2038 can be achieved, remains uncertain as the permission to fully begin decommissioning was originally expected to be granted in 2022. As a major step of the warm-up stage, defueling, was already completed, WNISR considers Krümmel to be in this stage, although a permit has not yet been granted.[679]

Japan

As of mid-June 2022, 27 reactors or 17.1 GW were permanently disconnected from the grid in Japan. Japan, one of the early adopters of nuclear power, has not completed decommissioning of a single commercial reactor. The only accomplished decommissioning project is the small 12-MW research reactor Japan Power Demonstration Reactor (JPDR), released as a greenfield site in 2002 after having been used as a test site for decommissioning techniques.[680]

The decommissioning of the Magnox reactor Tokai-1 has been ongoing since 2001, with turbines having been dismantled and plans to begin reactor dismantling in 2024 to complete decommissioning by 2030.[681]

The decommissioning of Fugen ATR started in 2006 and is planned to be completed by 2034; work on Hamaoka-1 and -2 began in 2009 and is to last until 2036.

Genkai-1, Ikata-1, Mihama-1 and -2, Shimane-1, and Tsuruga-1 received their decommissioning licenses in 2017.[682] The plans foresee the reactors to complete decommissioning in the mid-2040s, respectively mid-2050s for Ikata-1 and possibly Genkai-1.

678 - German Bundestag, "Bericht nach § 7 des Transparenzgesetzes – Rückbau von Kernkraftwerken" ["Report according to §7 of the Transparency Act"], Drucksache 20/42, Deutscher Bundestag, 4 November 2021, see https://dserver.bundestag.de/btd/20/000/2000042.pdf; and RWE, "Rückbauanlage Gundremmingen", Undated, see https://www.rwe.com/der-konzern/laender-und-standorte/rueckbauanlage-gundremmingen, accessed 27 June 2022.

679 - KKK, "Kernkraftwerk Krümmel - Antrag nach §7 Abs. 3 AtG auf Stilllegung und Abbau Kernkraftwerk Krümmel" ["Nuclear Power Plant Krümmel – Application pursuant to §7 para. 4 of Atomic Energy Act for Decommissioning and Dismantling of Krümmel Nuclear Power Plant"], Kernkraftwerk Krümmel GMBH & Co., submitted to Ministry for Energy Transition, Agriculture, Environment and Rural Areas of the State of Schleswig-Holstein, 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 German Bundestag, "Bericht nach § 7 des Transparenzgesetzes - Rückbau von Kernkraftwerken", op. cit.

680 - JAEA, "Decommissioning Facility", Japan Atomic Energy Agency, Undated, see https://www.jaea.go.jp/english/04/ntokai/decommissioning/01/decommissioning_02.html, accessed 8 June 2022.

681 - JAPC, "東海発電所の廃止措置" ["Decommissioning of Tokai NPP"], The Japan Atomic Power Company, 31 March 2021 (in Japanese), see http://www.japc.co.jp/tokai/haishi/construction.html, accessed 8 June 2022.

682 - *WNN*, "Decommissioning plans approved for five Japanese units", 19 April 2017, see https://www.world-nuclear-news.org/Articles/Decommissioning-plans-approved-for-five-Japanese-u, accessed 8 June 2022; and *WNN*, "Ikata 1 decommissioning gets regulatory approval", 29 June 2017, see https://www.world-nuclear-news.org/Articles/Ikata-1-decommissioning%C2%A0gets-regulatory-approval, accessed 8 September 2022.

Fukushima Daiichi-5 and -6 as well as the Units 1–4 have no official completion target-date. Crucial next steps in the decommissioning process are spent fuel removal at Units 1–4, that will be completed when Unit 2 is defueled in 2026.[683] Unit 5 and 6 are to be defueled by 2031.[684] US-based engineering company Jacobs will assist TEPCO in decommissioning the site.[685]

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 cost more than ¥375 billion (US$$_{2019}$3.5 billion).[686] According to a media report, defueling at Monju was completed in April 2022.[687]

In 2020, Kyushu Electric Power filed the decommissioning license for the Genkai-2 reactor with the Japanese National Regulation Authority (NRA). Defueling of Unit 2 is expected to occur from 2026 to 2040. Kyushu Electric Power also requested approval to change of 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 is that the slowdown at Unit 1 would allow the decommissioning process to catch up with Unit 2, so that decommissioning works at both units could be carried out simultaneously.[688] For the decommissioning of Genkai-1 and -2, Kyushu operates a special account related to decommissioning, that, at the end of 2021, held approx. US$378 million.[689]

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 2026.[690] 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. Overall decommissioning should take 40 years.[691]

Spain

Spain defines its national policy for reactor decommissioning in the official, periodically updated "General Radioactive Waste Plan". According to this strategy, all decommissioning and waste-management activities are developed by the state-owned radioactive waste-management company Enresa (Empresa Nacional de Residuos Radiactivos S.A.). While the

683 - TEPCO, "Integrated Report 2020-2021", Tokyo Electric Power Company Holdings, October 2021, see https://www.tepco.co.jp/en/wp-content/uploads/TP20-21_EN_web.pdf, accessed 8 June 2022.

684 - 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.

685 - *WNN*, "Jacobs to support Fukushima Daiichi decommissioning", 20 May 2022, see https://www.world-nuclear-news.org/Articles/Jacobs-to-support-Fukushima-Daiichi-decommissionin, accessed 8 June 2022.

686 - *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.

687 - *NHK*, "もんじゅ廃炉作業 原子炉内核燃料 一時的な保管場所へ移動終了" ["Transfer of fuel to interim storage completed at Monju"], April 2022 (in Japanese), see https://www3.nhk.or.jp/news/html/20220422/k10013594781000.html, accessed 8 June 2022.

688 - *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.

689 - Kyuden Group, "Integrated Report 2021", September 2021, see https://www.kyuden.co.jp/library/pdf/en/ir/integratedreport/2021/en_integratedreport_2021.pdf, accessed 8 June 2022.

690 - Shikoku Electric Power Group, "Integrated Report 2021", Yonden, December 2021, see https://www.yonden.co.jp/english/assets/pdf/ir/tools/ann_r/annual_e_2021.pdf, accessed 8 June 2022.

691 - Ibidem.

LTE strategy is applied for the GCR Vandellos-1 (until 2028),[692] all LWRs are bound to be directly dismantled to greenfield status.

Spanish administration describes decommissioning and waste management as an essential public service and assigns these tasks to Enresa by law.[693] Demolition work is underway at the José Cabrera (Zorita) plant, while Enresa is still awaiting approval of its decommissioning documentation that was submitted in 2020.[694] In June 2022, demolition of the turbine building, being the last large building on site, was completed.[695] (See WNISR2019 for details on the decommissioning process in Spain.)

United Kingdom

The U.K. has a long history of nuclear power use resulting in a large fleet of 26 GCR Magnox reactors, now all closed. Two FBRs also belong to this this so-called legacy fleet. Since WNISR2021, many of these reactors were transferred from an LTE state to active decommissioning. The whole process of decommissioning is nevertheless expected to last until the 2130s, more than a century from now.[696] After an initial approach of privatized decommissioning, the National Decommissioning Authority (NDA) has reassumed control over recent years of all so-called Site Licence Companies (SLC) that operate the different sites.[697] At the most recently closed sites, all AGRs, Dungeness B-1 and B-2 as well as Hunterston B-1 (all closed in 2021) and B-2 (closed in 2022), defueling is expected to begin in 2022.[698] These sites are currently still operated by EDF Energy who will conduct these initial tasks before transferring ownership to the NDA for further decommissioning.[699]

Currently, 22 reactors are undergoing decommissioning.

- Thirteen reactors are in the warm-up stage: Chapelcross 1–4 (all defueled), Dounreay DFR, Dounreay PFR, Dungeness A-1 & -2 (both defueled), Trawsfynydd-1 & -2 (both defueled), Windscale (defueled), and Wylfa-1 & -2 (both defueled);

692 - Enresa, "Dismantling of the Vandellós I Nuclear Power Plant", Undated, see https://www.enresa.es/eng/index/activities-and-projects/dismantling-and-environmental-restoration/dismantling-of-vandellos-i-nuclear-power-plant, accessed 8 June 2022.

693 - By Article 38 bis of Law 25/1964 of the Nuclear Energy Act.

694 - *WNN*, "Decommissioning application submitted for Garoña", 26 May 2020, see https://www.world-nuclear-news.org/Articles/Decommissioning-application-submitted-for-Garona; and Enresa, "Annual Report 2020", 2021, see https://www.enresa.es/eng/index/about-enresa/publications/category/9-institutional; both accessed June 2022.

695 - *WNN*, "Decommissioning milestone at Spain's Zorita plant", 27 June 2022, see https://www.world-nuclear-news.org/Articles/Decommissioning-milestone-at-Spain-s-Zorita-plant, accessed 4 July 2022.

696 - NDA, "Business Plan—1 April 2022 to 31 March 2025", SG/2022/39, Nuclear Decommissioning Authority, March 2022, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1062302/Business_Plan_2022-2025_220322.pdf, accessed 8 April 2022.

697 - Ibidem; and NDA, "Strategy—Effective from March 2021", SG/2021/48, 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 8 September 2022.

698 - EDF Energy, "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, accessed 25 April 2022; EDF Energy, "Nuclear decommissioning", Undated, see https://www.edfenergy.com/about/nuclear/decommissioning, accessed 27 June 2022.

699 - Committee of Public Accounts, "The future of the Advanced Gas-cooled Reactors—Third report of session 2022-23", HC 118, House of Commons, published 20 May 2022, see https://committees.parliament.uk/publications/22301/documents/164944/default/, accessed 23 May 2022.

- Nine reactors are in the hot-zone-stage: Hinkley Point A-1 & A-2, Hunterston A-1 & -2, Oldbury A-1 & -2, Sizewell A-1 & -2 and Winfrith.

Eight reactors are currently in LTE.

Sellafield Ltd was the first SLC to be returned to full NDA ownership in 2016.[700] This SLC is responsible for the clean-up at the Sellafield site, the largest, oldest, and most complex nuclear site in the U.K. This includes legacy fuel pools and storage ponds, as well as nuclear reactors Calder Hall 1–4 (in LTE) and Windscale. Fuel from all nuclear reactors and legacy ponds will be transferred to Sellafield into interim storage. [701]

Milestones that are currently being worked on include the retrieval of bulk sludge and fuel from legacy ponds and silos, originally expected to be completed by the early 2030s[702]. Legacy oxide fuel was retrieved from Sellafield's ponds in 2016. Legacy Magnox fuel that had been stored in fuel ponds at Sellafield was envisioned to be fully retrieved by 2025.[703] However, . first removal of Magnox legacy fuel was achieved only in June 2022. According to staff on site, the task will take around 20 additional years to fulfil.[704] Thus, whether the envisioned dates for milestone completion can be achieved remains to be seen.[705]Sellafield Ltd plans to demolish the upper diffusion section of the Windscale Pile Chimney Number 1 and begin cleaning out the MAGNOX reprocessing plant. Both steps are to be completed by end-2023.[706]

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. The net capacity of these old MAGNOX reactors accumulates to approx. 4.5 GW. Winfrith, Trawsfynydd, and Dounreay, operated by U.K. Atomic Energy Authority (UKAEA) and Dounreay Site Restoration Ltd (DSRL), have been nominated as "lead and learn sites" to optimize the decommissioning strategy for the legacy fleet, including Calder Hall at Sellafield, and determine best practices for the upcoming decommissioning of the GCR fleet operated by EDF Energy. Thus, for Winfrith and Trawsfynydd, revisions of initial strategies concluded that some contaminated underground structures (e.g. subsurface portion of the biological shield) will remain in place and land will nevertheless be suitable for its next planned use. Each site operated by Magnox Ltd will receive a revised decommissioning plan with milestone dates. These have however not yet been published for each site.[707]

700 - 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.

701 - NDA, "Mission Progress Report", Nuclear Decommissioning Authority, November 2021, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031213/NDA_Mission_Progress_Report_2021.pdf, accessed 19 April 2022.

702 - 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.

703 - NDA, "Mission Progress Report - Cleaning up the UK's earliest nuclear sites, caring for people and the environment", Nuclear Decommissioning Authority, November 2021, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031213/NDA_Mission_Progress_Report_2021.pdf, accessed 19 April 2022.

704 - *WNN*, "Waste removal starts at Sellafield facility", 10 June 2022, see https://www.world-nuclear-news.org/Articles/Waste-removal-starts-at-Sellafield-facility, accessed 27 June 2022.

705 - Ibidem.

706 - NDA, "Business Plan—1 April 2022 to 31 March 2025", op. cit.

707 - Ibidem; and NDA, "Strategy—Effective from March 2021", op. cit.

At the Dounreay site in northern Scotland, two reactors are to be decommissioned. These sites are managed by DSRL. The 15-MW Dounreay Fast Reactor (DFR) was closed in 1977 and is to be fully dismantled by 2025. The 250-MW Prototype Fast Reactor (PFR) was closed in 1994, and dismantling is scheduled to be completed by 2027. According to the schedule, defueling of both reactors should be completed by 2025.[708] Most fuel has now been reprocessed at the Sellafield reprocessing plant. Remaining fuel will be moved to Sellafield for interim dry storage following above-described timeframe.[709]

EDF Energy is the owner and operator of all remaining nuclear power plants in the U.K. Of these, two sites, Dungeness-B (2 x 545 MW) and Hunterston-B (2 x 490 MW), have been closed. Since September 2018, Dungeness-B had been in a long-term outage (LTO) following safety inspections that exposed faster than expected decay of relevant, unreplaceable components. Thus, in June 2021, it was decided to defuel both reactors at Dungeness-B.[710] After initially extending the lifetime of both reactors at the Hunterston-B site to 2023 with a +/- 2-year proviso in 2012, closure was recorded in November 2021 for the first reactor and in January 2022 for the second. Defueling is to begin in the course of 2022.[711] Hinkley Point B, a nuclear power plant consisting of two GCR reactors with a net capacity of 485 and 480 MW, respectively, was to be closed by the end of July 2022 (See also United Kingdom Focus).[712] In terms of decommissioning, the British government signed an arrangement with EDF Energy to transfer the ownership of its GCR fleet to the NDA after the plants have been defueled. This agreement includes a defueling performance-premium of up to £100 million (US$122.4 million) or the loss of the same amount if performance is deemed insufficient. Whether this amount will be able to incentivize efficient defueling and smooth transfer of sites into NDA custody, remains to be seen. The House of Commons' Commission of Public Accounts remains skeptical as to the potential positive impact of this incentive.[713] This arrangement was made specifically for EDF Energy's British GCR fleet and excludes the PWR plant Sizewell B.[714]

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 CEA is responsible as owner (G-2, G-3) or co-owner (Phénix, 20 percent of shares belong to EDF), all reactors are decommissioned by EDF.[715]

708 - NDA, "Business Plan—1 April 2022 to 31 March 2025", op. cit.

709 - *WNN*, "Sellafield processes last of fast reactor fuel", 24 June 2022, see https://www.world-nuclear-news.org/Articles/Sellafield-processes-last-of-fast-reactor-fuel, accessed 27 June 2022.

710 - EDF Energy, "EDF Decides to Move Dungeness B into Defuelling Phase", op. cit.

711 - EDF Energy, "Nuclear Decommissioning", op. cit.

712 - Ibidem.

713 - House of Commons, "The future of the Advanced Gas-cooled Reactors—Third report of session 2022-23", HC 118, op. cit.

714 - 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.

715 - ASN, "ASN Report on the state of nuclear safety and radiation protection in France in 2020", August 2021, op. cit.

Despite France's theoretical official strategy of as-fast-as-possible decommissioning, the process is advancing slowly.[716] EDF is currently responsible for the decommissioning of six first-generation GCRs at Bugey, Chinon, Saint-Laurent, three PWRs (Chooz-A, Fessenheim-1 and -2), one HWGCR at Brennilis (EL-4) and the Superphénix FBR at Creys-Malville.

In the years to come, EDF will also have to manage decommissioning activities of its large PWR fleet still in operation. When exactly these units will enter their respective decommissioning phases depends on decisions concerning lifetime extensions. EDF hopes to use the Fessenheim reactors as test sites to learn best practices that can then be applied to to-be-decommissioned PWR sites and reduce costs and necessary efforts for decommissioning.[717]

The PWR reactor at Chooz-A was shut down in 1991 and has been undergoing decommissioning since 2007. Work on the reactor internal vessels was completed in 2021. Cutting of the pressure vessel is to start in 2023. EDF expects these tasks to be completed by 2024, when final decommissioning and decontamination can begin. The original plan issued in 2007 expected Chooz-A to be fully delicensed by 2047, but following a change of strategy, estimations had advanced the date to 2035. However, work has been delayed due to the impact of COVID-19. Due to the site's unique location in a cave, unexpected difficulties have led to multiple cost increases, the last amounting to additional €77 million (US$81 million) in 2021.[718]

For its six GCRs Chinon A-1, A-2 and A-3, Saint-Laurent-des-Eaux A-1 and A-2, and Bugey-1, EDF in 2001 initially adopted a strategy of Long-term enclosure by flooding the reactor vessel with water and then performing decommissioning procedures underwater.[719] However, due to France's decommissioning strategy of as-fast-as-possible decommissioning and technical issues of underwater dismantling, EDF decided to change the strategy to in-air dismantling in 2016. Thus, initial targets for dismantling no later than 2031 have been scrapped. The French Nuclear Safety Authority ASN (Autorité de Sûreté Nucléaire) stated in 2021 that "EDF has not as yet provided any demonstrations such as to permit authorisation of the next stages in the decommissioning of the Chinon A1 and A2 reactors."[720]

EDF's current plans include reactor internal vessel and graphite block removal at Chinon A-2 to begin in 2033 and last up to 2054. By 2035, all other reactors are scheduled to be placed into a "safe storage configuration" for decommissioning to commence by 2055.[721] The French Nuclear Safety Authority ASN (Autorité de Sûreté Nucleaire) however is opposed to this strategy as it would place decommissioning tasks well into the future and contradict the as-fast-as-possible decommissioning strategy.[722] Thus, all GCRs must apply for new decommissioning decrees in

716 - Ibidem.

717 - Christophe Martin, Aurélien Portelli and Franck Guarnieri, "Myths and representations in French nuclear history: The impact on decommissioning safety", ESAIP Engineering School, Centre de Recherche sur les Risques et les Crises, Mines ParisTechin, in "Safety, reliability and risk analysis: beyond the horizon", proceedings of the 22nd European Safety and Reliability Conference, 29 September-2 October 2013, see https://hal-mines-paristech.archives-ouvertes.fr/hal-00868830/document, accessed 8 September 2022 ; and ASN, "ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020", August 2021, op. cit.

718 - EDF, "Universal Registration Document 2021—Including the Annual Financial Report", March 2022, op. cit.

719 - ASN, "ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020", op. cit.

720 - Ibidem.

721 - EDF, "Universal Registration Document 2021—Including the Annual Financial Report", 2022, op. cit.

722 - ASN, "ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020", op. cit.

2022. Total decommissioning costs for all six GCRs have doubled and are now estimated at €6.6 billion (US$$_{2022}$6.9 billion).[723]

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 target for the whole site to be released from regulatory oversight by 2038. Decommissioning costs are estimated at €1.8 billion (US$$_{2022}$1.9 billion). This marks a four-fold increase in costs since the beginning of decommissioning in 2006.[724]

In 2011, the EL-4 reactor at Brennilis (Monts d'Arrée) received a partial dismantling license for parts outside the nuclear island. Since then, progress has been made such as spent fuel removal and machine room dismantling. EDF is currently awaiting approval to begin further work on the reactor itself. These operations are planned to be completed by 2040. In the 1990s, decommissioning provisions varied between €10–20 million (US$$_{2022}$10.5–20.9 million). Most recent estimates place total decommissioning costs for this one reactor at €880 million (US$$_{2022}$919.6 million), about double the cost estimate when decommissioning began in 2011.[725]

The two PWRs at Fessenheim were closed in 2020. EDF currently plans a five-year preparatory phase until the decommissioning license is obtained, which is expected in 2025. This includes fuel removal, scheduled to be completed in 2023. Furthermore, work has begun on the removal of replaced steam generators that were still stored onsite and their transfer to the Cyclife (an EDF subsidiary) recycling plant in Sweden. This is done to free storage capacities for the replacement steam generators that are still in the reactors and must still be dismantled.[726]

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 continued. A strategy change involving a new decommissioning license is to set the deadline for decommissioning completion to end-2023.[727] 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. The last documented target completion date for the steps of graphite removal and reactor dismantling was published in 2015 as sometime in the 2040s.[728]

723 - EDF, "Universal Registration Document 2021—Including the Annual Financial Report", 2022, op. cit.

724 - Ibidem.

725 - Ibidem.

726 - ASN, "ASN Report on the State of Nuclear Safety and Radiation Protection in France in 2020", op. cit.

727 - Ibidem.

728 - CEA, "Dossier de presse - Démantèlement" ["Press kit—Decommissioning"], Commissariat à l'énergie atomique et aux énergies alternatives/French Alternative Energies and Atomic Energy Commission (in French), 4 April 2015, see https://www.francetnp.gouv.fr/IMG/pdf/dossier_de_presse_demantelement_-_2015_v2.pdf, accessed 17 May 2022.

Italy

In Spring 2022, Sogin, the Italian agency tasked with decommissioning all nuclear facilities in the country, announced that by the end of 2022, it will have completed 45 percent of physical decommissioning tasks.[729] Sogin was able to release the first nuclear facility, fuel fabrication plant Bosco Marengo, to brownfield status in June 2022.[730] However, of the four closed commercial nuclear reactors, only Garigliano, a 150-MW BWR, has made progress since WNISR2021 by moving into the hot-zone stage. Reactor internal dismantling work is currently being tendered, with contracts amounting to over €12 million (US$12.6 million).[731] This work is scheduled to be completed by 2025.[732] The other three reactors, Caorso, Enrico Fermi (Trino) and Latina, are still in the warm-up stage. At Latina, spent fuel pools are currently being decommissioned, originally expected to be completed by 2021.[733] However, instead of completing radioactive sludge removal in 2019, as expected, this task was completed only in May 2022.[734] Further pool decommissioning tasks include the removal of metallic structures and dismantling of the fuel pond basin. But, as of writing, no updates on the current plan have been published. [735] Dismantling of steam turbines at Enrico Fermi is reportedly underway, indicating some progress, although the task was supposed to be completed by 2021.[736] All four plants are to be released as brownfield sites. Individual cost estimations to reach this stage range from €245 million (US$$_{2022}$256 million) for Enrico Fermi (Trino)[737] to €360 million (US$$_{2022}$376.2 million) for Garigliano.[738] (See WNISR2019 and WNISR2020 for detailed information on decommissioning of reactors in Italy.)

Lithuania

In Lithuania, two reactors at Ignalina with 1185 MW each were closed in 2004 and 2009, respectively, following a pre-requisite engagement 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

729 - Sogin, "Sogin accelerates decommissioning: more than 17% in the two-year period 2021-2022", 1 March 2022, see https://www.sogin.it/en/media/news/sogin-accelerates-decommissioning-more-than-17-per-cent-in-the-two-year-period-2021-2022.html, accessed 24 June 2022.

730 - *WNN*, "Dismantling of Italian nuclear fuel plant completed", 16 June 2022, see https://www.world-nuclear-news.org/Articles/Dismantling-of-Italian-nuclear-fuel-plant-complete, accessed 24 June 2022.

731 - 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.

732 - Sogin, "Reactor dismantling at Garigliano", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/garigliano nuclearpowerplant/decommissioningprojects/reactor-dismantling.html, accessed 24 June 2022.

733 - Sogin, "Reclamation of the fuel pool", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/decommissioningprojects/fuel-pool-decontamination.html, accessed 24 June 2022.

734 - Sogin, "Sogin completed the extraction of radioactive sludge in Latina", 18 May 2022, see https://www.sogin.it/en/media/news/sogin-completes-the-extraction-of-radioactive-sludge-in-latina.html, accessed 24 June 2022.

735 - Sogin, "Reclamation of the fuel pool", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/decommissioningprojects/fuel-pool-decontamination.html, accessed 24 June 2022.

736 - Sogin, "Trino Nuclear Power Plant", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/trinonuclearpowerplant/Pagine/default.aspx, accessed 24 June 2022.

737 - Ibidem.

738 - Sogin, "Garigliano Nuclear Power Plant", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/garigliano nuclearpowerplant/Pagine/default.aspx, accessed 24 June 2022.

of the spent fuel from Unit 2 was achieved in April 2022.[739] The targeted decommissioning end-date was delayed repeatedly, and in 2011, it was postponed by a further nine years from 2029 to 2038. It is planned to decommission Ignalina to "brownfield" status.[740] (For more details on decommissioning in Lithuania, see WNISR2019.)

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-2022, two commercial reactors had been closed: South Korea's oldest unit Kori-1, a 576 MW PWR, and Wolsong-1, a 661 MW Pressurized Heavy-Water Reactor (PHWR). Wolsong-1 ceased generating power in May 2017 but was officially closed only in December 2019.[741] In May 2020, the operator Korea Hydro & Nuclear Power (KHNP), applied for a license to dismantle Kori-1.[742] No decommissioning progress was reported as of mid-2022.

Canada

In Canada, no commercial reactor has been decommissioned thus far. By mid-2022, six reactors (2.1 GW), of which five CANDU (CANadian Deuterium Uranium) reactors and one Heavy-Water Moderated Boiling Light-Water Reactor (HWBLWR) have been closed. Although some parts of the closed facilities have been dismantled, decommissioning has not even started on a single CANDU reactor. (For more details on the Canadian decommissioning process, see WNISR2018.)

Russia

As of mid-2022, Russia has 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. At the most recently closed site, Kursk-1, which was closed in December 2021, decommissioning is still to commence.[743] Considering the long-anticipated decommissioning duration of 50 years and unclear decommissioning strategies, WNISR considers the Russian reactors in LTE as long

739 - *WNN*, "Defueling of Ignalina units completed", 22 April 2022, see https://www.world-nuclear-news.org/Articles/Defuelling-of-Ignalina-units-completed, accessed 8 June 2022.

740 - European Commission, "Programme Statements—Heading 5: Security and Defence—Nuclear Decommissioning (Lithuania)", DB2023, 7 June 2022, see https://ec.europa.eu/info/sites/default/files/about_the_european_commission/eu_budget/ps_db2023_ndl_h5.pdf, accessed 8 September 2022; and European Court of Auditors, "EU nuclear decommissioning assistance programmes in Lithuania, Bulgaria and Slovakia: some progress made since 2011, but critical changes ahead.", Special Report No. 22, European Court of Auditors, 2016, see http://www.eca.europa.eu/Lists/ECADocuments/SR16_22/SR_NUCLEAR_DECOMMISSIONING_EN.pdf, accessed 20 June 2019.

741 - KHNP, "Nuclear Power Operation - Plant Status", 31 December 2018, see http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101, accessed 27 March 2019

742 - *WNN*, "KHNP applies to dismantle Kori 1", 14 May 2021, see https://world-nuclear-news.org/Articles/KHNP-applies-to-dismantle-Kori-1, accessed 8 September 2022.

743 - *NEI Magazine*, "Russia permanently closes down Kursk 1", 21 December 2021, see https://www.neimagazine.com/news/newsrussia-permanently-closes-down-kursk-1-9337101, accessed 8 June 2022.

as there is no documented evidence of decommissioning progress or announcement indicative of another strategy being prepared. (See WNISR2019 for details on decommissioning in Russia.)

CONCLUSION ON REACTOR DECOMMISSIONING

Assuming a 40-year average operational lifetime—the current average age is 31 years—a further 158 reactors will have been closed by 2030 (reactors connected to the grid between 1982 and 1990); and an additional 143 will be closed by 2062. This does not even account for 110 reactors which started operating before 1982, additional 29 reactors in Long-term Outage (LTO) and 53 reactors under construction as of mid-2022. As was shown in previous issues of WNISR, 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.

"204 reactors have been closed. Of these, 172 are in some state of decommissioning and 22 have been fully decommissioned, although some are still awaiting release from regulatory control, and only 10 have been returned to greenfield conditions"

Since WNISR2021, eight reactors have been closed. Of these, six are in Europe (three in Germany, two in the U.K. and one in Russia). The others are the KANUPP-1 reactor in Pakistan and Palisades in the U.S. At most of these sites, preparations for decommissioning work are still underway.

Worldwide, as of July 2022, 204 reactors have been closed. Of these, 172 are in some state of decommissioning and 22 have been fully decommissioned, although some are still awaiting release from regulatory control, and only 10 have been returned to greenfield conditions, meaning they are available for unrestricted use.

In Europe, the 123 closed reactors represent 60 percent of the world's total and decommissioning efforts are advancing sporadically. The U.K. has changed its strategy and is slowly removing its legacy fleet from LTE status but estimates the return to unrestricted use for all sites to last well into the 22nd century. France is also currently assessing the initially chosen strategy for its eight GCR reactors, further delaying progress possibly into the next century.

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 only accomplished 45 years after closure.

Most of these decommissioned reactors have low power ratings, 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 WNISR2021, a large number of reactors has entered the Hot-Zone Stage (15 in 2021 vs. 30 in 2022). Many of these reactors (9) are in the U.K. where decommissioning efforts have been accelerated after a strategy change. Germany is also conducting hot-zone operations at nine reactors. Other countries with reactors in the hot-zone are France (2), Italy (1), the U.S. (3), Slovakia (2), and Sweden (4).

Over the past year, many reactors have moved from Long-Term Enclosure (LTE) to the warm-up-stage. This results in 78 reactors currently in the warm-up stage, 26 of which are in Japan, followed by 13 in the U.K. For the time being, 52 reactors remain in LTE including 12 in the U.S., nine in Russia, eight in France, and eight in the U.K. Table 10 provides an overview of reactor decommissioning worldwide.

POTENTIAL NEWCOMER COUNTRIES

Bangladesh

2

Construction of the twin VVER-1200 nuclear reactors is ongoing at Rooppur, which began in November 2017 and July 2018, respectively.[744] As of October 2021, fuel loading of the first reactor was scheduled in the fourth quarter of 2023; Unit 1 is scheduled for grid connection the same year, and Unit 2 for 2024.[745] The dates announced in July 2018 for commencement of commercial operations were 2023 and 2024 respectively.[746]

There is, however, concern about the implications of the financial sanctions on Russia and the war in Ukraine, although Rosatom says "it does not see disruption in any of the commitments and work schedules in the project".[747] According to Rosatom executives, Russia has continued to ship equipment for constructing the plant without interruptions.[748]

The Bangladeshi Government remains prudent. Nasrul Hamid, State Minister of Power, Energy and Mineral Resources, has said that the government estimates demand in 2030 to be 40,000 MW of electricity and that the government was "working to ensure that we get the 40,000 MW [by] 2030 assuming that we may not get the 2,400 MW from the Rooppur nuclear power plant… If construction of the Rooppur nuclear power plant is hampered, possibly we will not see any problem in getting power from other backup coal projects and some renewable sources".[749]

There is widespread concern about the safety and security of the plant. In a survey conducted "across the country from October to December 2020" and published in December 2021, a majority of the respondents (54 percent) "expressed concerns over the safety, security, and sustainability" of nuclear power plants.[750] The survey also found that only 28 percent felt that the "regulatory body of Bangladesh is competent and independent", while 77 percent

744 - 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 4 August 2020; 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 15 July 2018.

745 - Eyamin Sajid, "Fuel likely to be loaded in Rooppur nuke plant by Q4 2023", *The Business Standard*, 14 October 2021, see https://www.tbsnews.net/bangladesh/energy/fuel-likely-be-loaded-rooppur-nuke-plant-q4-2023-315991, accessed 10 June 2022.

746 - Rosatom, "Main Construction of the 2nd Unit of Rooppur NPP Begins with the 'First Concrete' Ceremony", op. cit.

747 - Masum Billah, "Western sanctions cast a cloud over Russia-backed Bangladesh nuclear power plant", *bdnews24.com*, 2 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; Mohammad Azizur Rahman, "Fund crunch may hit Rooppur Nuclear Plant following Russia sanctions", *The Financial Express*, 1 March 2022, see https://thefinancialexpress.com.bd/trade/fund-crunch-may-hit-rooppur-nuclear-plant-following-russia-sanctions-1646101783, accessed 10 June 2022.

748 - *The Financial Express*, "Russia keeps shipment of equipment for Rooppur NPP uninterrupted", 5 April 2022, see https://thefinancialexpress.com.bd/home/russia-keeps-shipment-of-equipment-for-rooppur-npp-uninterrupted-1649145095, accessed 5 April 2022.

749 - Kamran Reza Chowdhury, "Questions over Russia-funded nuclear power plant in Bangladesh", *The Third Pole*, 8 April 2022, see https://www.thethirdpole.net/en/energy/questions-over-rooppur-nuclear-power-plant-bangladesh/, accessed 10 June 2022.

750 - Md Shafiqul Islam, Abid Hossain Khan and Md Sohel Rana, "Knowledge, belief, and attitude of Bangladeshi youth toward the development of nuclear power", *Nuclear Energy and Technology*, 16 December 2021.

felt that construction will not be free from corruption. There have been media reports about corruption.[751]

Even before the first two reactor units have been fully constructed, and the full costs ascertained, Bangladesh's Prime Minister, Sheik Hasina, has called for building a second nuclear power plant.[752] There is already considerable over-capacity in the country, and the "capacity cost" payments—each year government pays power plant operators for installed capacity even if no electricity is generated—have reportedly increased by nearly 400 percent between 2010–11 and 2019–20.[753] Much of the generation is based on fossil fuels, and renewables have not been prioritized.[754] As of June 2022, the capacity of renewables was only 789 MW, mostly solar (555 MW of which 63 percent was in the form of off-grid systems) and hydro (230 MW).[755] In 2021, according to BP, solar power contributed 450 GWh, wind energy contributed 5 GWh, and other renewables contributed 3 GWh; hydro (including large hydro) contributed 680 GWh.[756]

Egypt

On 29 June 2022, Russian state company Rosatom secured a construction permit for the first nuclear power reactor in Egypt,[757] and on 20 July 2022, in spite of the ongoing war in Ukraine, construction was officially launched.[758]

The Egyptian nuclear vision began in the mid-1950s with the establishment of the Egyptian Atomic Energy Commission (currently known as the Atomic Energy Authority). Egypt started to explore the possibilities of building nuclear power reactors in the mid-1960s and established the Nuclear Power Plants Authority (NPPA) in the mid-1970s. Initial plans envisioned 10 reactors being operational by the end of the century.

Despite discussions with Chinese, French, German, and Russian suppliers, little development occurred for several decades except for selecting, in 1984, Dabaa on Egypt's Mediterranean

751 - *Star Online*, "Corruption in Rooppur Nuclear Power Plant: HC seeks to know steps", *The Daily Star*, 2 July 2019, see https://www.thedailystar.net/city/corruption-in-rooppur-power-plant-hc-seeks-know-steps-1765591, accessed 28 May 2020.

752 - Umesh Ellichipuram, "Bangladesh plans to build its second nuclear power plant", *Power Technology*, 12 October 2021, see https://www.power-technology.com/news/bangladesh-nuclear-plant/, accessed 10 June 2022. See also, M. V. Ramana and Zia Mian, "The Rooppur Nuclear Power Plant: The Long, Troubled, Costly and Dangerous Life and After-Life of a Very Old Idea", *sarbojonkotha*, November 2021, see https://sarbojonkotha.info/rooppur-npp-long-troubled-costly-dangerous-life/, accessed 20 December 2021.

753 - Reaz Ahmad, "How much power does Bangladesh require?", *Dhaka Tribune*, 10 September 2021, see https://archive.dhakatribune.com/bangladesh/power-energy/2021/09/10/how-much-power-bangladesh-requires, accessed 10 June 2022.

754 - Abu Siddique, "Sluggish growth of renewables threatens Bangladesh's clean-energy goals", *Mongabay Environmental News*, 19 April 2022, see https://news.mongabay.com/2022/04/sluggish-growth-of-renewables-threatens-bangladeshs-clean-energy-goals/, accessed 10 June 2022.

755 - SREDA, "National Database of Renewable Energy—RE Generation Mix", Sustainable and Renewable Energy Development Agency, Undated, see http://www.renewableenergy.gov.bd/index.php, accessed 10 June 2022.

756 - BP, "Statistical Review of World Energy 2022", BP, June 2022, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 12 July 2022.

757 - Rosatom ASE, "Construction Permit Issued for the El-Dabaa NPP Unit 1", Press Release, 30 June 2022 see https://ase-ec.ru/en/for-journalists/news/2009/jun/construction-permit-issued-for-the-el-dabaa-npp-unit-1/, accessed 1 July 2022.

758 - WNISR, "Russia's Rosatom Starts Building Egypt's First Nuclear Reactor—Anyways 3", 20 July 2022, see https://www.worldnuclearreport.org/Russia-s-Rosatom-Starts-Building-Egypt-s-First-Nuclear-Reactor-Anyways-3.html, accessed 19 August 2022.

coastline to host Egypt's first nuclear power plant.[759] Nuclear plans were suspended indefinitely after the 1986 Chernobyl disaster and only in 2006, under former President Hosni Mubarak, came the announcement that plans were to be revived.

Finally, in February 2015, Rosatom and Egypt's NPPA signed a cooperation agreement, followed in November 2015 by an intergovernmental agreement for the construction of four VVER-1200 reactors at Dabaa, for a total installed capacity of 4.8 GW.[760]

In May 2016 it was announced that Egypt had concluded a US$25 billion loan with Russia for nuclear construction, at three percent interest for 85 percent of the construction cost, to be paid back, starting on 15 October 2029, through the sale of electricity.[761] In December 2017, the construction cost of the project was generally reported to be around US$30 billion. However, one Egyptian newspaper published an estimate as high as US$45 billion.[762] Three other deals were signed to cover the supply of nuclear fuel for 60 years, operation and maintenance for the first 10 years of operation, and training of personnel.[763]

The site chosen for construction lies about 300 km from Cairo at El-Dabaa city in the Governorate of Matrouh on the north-west coast of Egypt on the Mediterranean Sea. In March 2019, the NPPA was granted a site permit for the reactors, the first step toward getting a construction permit.[764]

In 2018, AAEM—a joint venture of Atomenergomash and GE Power—was set to supply the basic design of the four nuclear turbine islands, the turbine generators, including the Arabelle steam turbines, and technical expertise for installation and commissioning.[765] In December 2019, Australian energy group Worley Limited was awarded a consultant contract to advise Egypt in the building process.[766] In February 2020, Atomstroyexport, a subsidiary of Rosatom, announced that three Egyptian firms—Petrojet, Hassan Allam, and The Arab Contractors—had won a tender for the first phase of work on the plant, expected to begin in the summer of 2020 and continue through 2022.[767]

759 - Joy Nasr and Ali Ahmad, "Middle East Nuclear Energy Monitor: Country Perspectives 2018", Annual Report, 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 17 July 2021.

760 - Omar Fahmy, Asma Alsharif and Luke Baker, "Egypt, Russia sign deal to build a nuclear power plant", *Reuters*, 19 November 2015, see https://www.reuters.com/article/us-nuclear-russia-egypt-idUSKCN0T81YY20151119, accessed 17 July 2021.

761 - Al-Masry Al-Youm, "Three Egyptian companies win tender for Dabaa nuclear plant", *Egypt Independent*, 17 February 2020, see https://egyptindependent.com/three-egyptian-companies-win-tender-for-dabaa-nuclear-plant/, accessed 17 July 2021.

762 - Reem Hosam El-din, "Dabaa nuclear plant, SCZone: ambitions, plans ahead", *Daily News Egypt*, 12 December 2017, see https://dailynewsegypt.com/2017/12/12/dabaa-nuclear-plant-sczone-ambitions-plans-ahead/, accessed 13 December 2017.

763 - Phil Chaffee, "Rosatom Locks in $30 Billion Nuclear Deal in Egypt", *Nuclear Intelligence Weekly*, 15 December 2017.

764 - *NEI Magazine*, "Egypt's El-Dabaa NPP granted site permit", 16 April 2019, see https://www.neimagazine.com/news/newsegypts-el-dabaa-npp-granted-site-permit-7156405/, accessed 17 July 2021.

765 - GE Power, "GE Power to supply 4 nuclear turbine islands for El Dabaa, Egypt's first nuclear plant", Press Release, 9 October 2018, see https://www.ge.com/news/press-releases/ge-power-supply-4-nuclear-turbine-islands-el-dabaa-egypts-first-nuclear-plant, accessed 30 July 2022.

766 - *NEI Magazine*, "Worley wins contract to advise Egypt on nuclear plant construction", 31 December 2019, see https://www.neimagazine.com/news/newsworley-wins-contract-to-advise-egypt-on-nuclear-plant-construction-7581139, accessed 17 July 2021.

767 - Al-Masry Al-Youm, "Three Egyptian companies win tender for Dabaa nuclear plant", *Egypt Independent,* op. cit.

In March 2021, Korea Hydro & Nuclear Power (KHNP) signed a cooperation agreement with Petrojet to provide support in "training of local technicians and experts in Egypt",[768] and was pre-authorized in January 2022, as sole bidder for the supply of some of the equipment of the turbine islands of the four units, consisting in the construction of main and auxiliary infrastructure and the procurement of equipment and materials.[769] At the time, an agreement was to be reached by the end of April 2022,[770] but there have been no updates since.

In 2018, the Egyptian Government had projected that Dabaa Unit 1 would be commercially operating as of 2026 and subsequent units in 2028. This schedule was based on construction start in 2020, with the last unit entering its construction phase in July 2022.[771] In compliance with the set targets, Anatolos Kovatnov, head of engineering work at the El Dabaa project, stated in December 2018 that Rosatom hoped to obtain the permits to start construction at the first unit of the Dabaa plant in July 2020.[772] Abdel Hamid al-Desouky, Deputy Chair of NPPA, also suggested a construction permit could be issued by mid-2020.[773]

However, the construction license application for Dabaa Unit 1 and Unit 2 was finalized more than two years behind schedule, on 30 June 2021,[774] while that of Units 3 and 4 was filed only on 30 December 2021.[775] In early February 2021, *TASS* had indeed reported that both countries had agreed on an updated schedule in December 2020 since the pandemic "slowed down the preparation at the site" according to Russia's Ambassador in Cairo, yet without providing any detail on the new timeline.[776] The Egyptian Government later dismissed the idea that COVID-19 ever impacted the project.

Contradictory statements on the potential impact of the pandemic continued and on 14 July 2021, the Egyptian Nuclear and Radiological Regulatory Authority (ENRRA) was reported as stating that Dabaa will not be completed before 2030 due to the disruption caused by the coronavirus pandemic.[777] Despite this, Electricity and Renewable Energy Minister

768 - *NEI Magazine*, "KHNP seeks participation in Egypt's El-Dabaa NPP project", 18 March 2021, see https://www.neimagazine.com/news/newskhnp-seeks-participation-in-egypts-el-dabaa-npp-project-8609294, accessed 30 July 2022.

769 - *NEI Magazine*, "KHNP pre-authorised to bid for construction work at El Dabaa nuclear plant", 6 January 2022, see https://www.neimagazine.com/news/newskhnp-selected-for-construction-work-at-el-dabaa-nuclear-plant-9371099; and *Business Korea*, "KHNP Selected to Participate in Egyptian Nuclear Power Plant Project", 3 January 2022, see http://www.businesskorea.co.kr/news/articleView.html?idxno=85315; both accessed 20 July 2022.

770 - *WNN*, "KHNP named as sole bidder for portion of El Dabaa equipment and materials", 4 January 2022, see https://www.world-nuclear-news.org/Articles/KHNP-named-as-sole-bidder-for-El-Dabaa-contract, accessed 20 July 2022.

771 - *NEI Magazine*, "Active progress on Egypt's El Dabaa", 22 October 2018, see https://www.neimagazine.com/news/newsactive-progress-on-egypts-el-dabaa-npp-6820883, accessed 17 July 2021; and *NEI*, "Work Progressing at Egypt's El Dabaa NPP, 12 December 2018, see https://www.neimagazine.com/news/newswork-progressing-at-egypts-el-dabaa-npp-6896457, accessed 21 July 2022.

772 - *NEI Magazine*, "Work progressing at Egypt's El Dabaa NPP", 12 December 2018, see https://www.neimagazine.com/news/newswork-progressing-at-egypts-el-dabaa-npp-6896457, accessed 25 July 2021.

773 - Ibidem.

774 - Rosatom, "Rosatom State Atomi Energy Corporation ROSATOM global leader in nuclear technologies nuclear energy", Press Release, 1 July 2021, see https://rosatom.ru/en/press-centre/news/nuclear-power-plants-authority-of-egypt-handed-over-the-licensing-documentation-for-el-dabaa-npp-con/, accessed 29 July 2021.

775 - NPPA, "El-Dabaa NPP Project—Progress", Nuclear Power Plants Authority, Updated 13 June 2022, see https://nppa.gov.eg/en/el-dabaa-npp-project-2/#Progress, accessed 14 July 2022.

776 - *TASS*, "Russia, Egypt adjusted plans for construction of El-Dabaa NPP due to pandemic", 2 February 2021.

777 - *NEI Magazine*, "High ranking Egyptian nuclear delegation visits Russia dispelling rumours of tension", 4 August 2021, see https://www.neimagazine.com/news/newshigh-ranking-egyptian-nuclear-delegation-visits-russia-dispelling-rumours-of-tension-8963506/, accessed 21 July 2022.

Mohammed Shaker stated two days later that the plant was not facing any obstacles and would begin operation in 2026, as planned.[778] A four-year construction schedule is highly unrealistic, especially in a newcomer country, and indeed, on 28 July 2021, the postponement of full operation to 2030 was confirmed, with an expected licensing to occur mid-2022 and operation start of Unit 1 by 2028,[779] which is coherent with information provided on NPPA's website, anticipating a construction phase of five years and half—that would still be a remarkable achievement.[780]

Mid-2021, media reports stated that the revised schedule reflected a halt in the implementation of the project caused by political tensions between the two countries.[781] Both Rosatom and NPPA were prompt in putting out statements to deny the project suffered any difficulties or interruption.[782] Just as fast, a delegation headed by Egyptian Minister of Electricity and Renewable Energy met with a Russian delegation providing Minister Mohammed Shaker the opportunity to assure that the project had "full support of the political leadership of Egypt" and for the Head of Rosatom to "emphasise the importance of this project for Rosatom and Russia as a whole".[783]

While rumors of tensions between the two countries seemed to fade, it was announced in November 2021, that ENRRA had signed a US$1 million–contract with ÚJV Řež, a Czech R&D company, for assistance in the licensing of Unit 1, with ÚJV Řež describing the services to be provided as "mainly [focused] on independent control of documents and services supplied by the Russian side and on support activities for Egyptian supervision in a number of other areas (...)."[784]

As analysts and experts have emphasized, it is highly likely that the wider consequences of Russia's ongoing war on Ukraine will impact the El-Dabaa project. Paul Sullivan, Senior Fellow with the Global Energy Center at U.S. Think Tank Atlantic Council wrote: "The strength of the constraints on this project (at Dabaa) by the sanctions is yet to be seen, but it could be considerable. This could slow down the project completion for many years. The sanctions will likely make the project even more expensive to accomplish. Inflation and supply chain issues will do this anyway."[785]

778 - Mohammed Abu Zaid, "Egypt's nuclear project on target, minister says", *Arab News*, 16 July 2021, see https://www.arabnews.com/node/1894936/business-economy, accessed 17 July 2021.

779 - George Mikhail, "Egypt postpones nuclear power plant amid tensions with Russia over Nile dam", *Al-Monitor*, 28 July 2021, see https://www.al-monitor.com/originals/2021/07/egypt-postpones-nuclear-power-plant-amid-tensions-russia-over-nile-dam, accessed 20 July 2022.

780 - NPPA, "El-Dabaa NPP Project—Project Overview", Updated 13 June 2022, see https://nppa.gov.eg/en/el-dabaa-npp-project-2/, accessed 30 June 2022.

781 - George Mikhail, "Egypt postpones nuclear power plant amid tensions with Russia over Nile dam", *Al-Monitor*, 28 July 2021, op. cit.

782 - Rosatom Global, Tweet, 29 July 2021, see https://twitter.com/RosatomGlobal/status/1420766759607488520; and NPPA, "Important Announcement", 5 August 2021, see https://nppa.gov.eg/en/important-announcement/; both accessed 30 July 2022.

783 - *NEI Magazine*, "High ranking Egyptian nuclear delegation visits Russia dispelling rumours of tension", 4 August 2021, see https://www.neimagazine.com/news/newshigh-ranking-egyptian-nuclear-delegation-visits-russia-dispelling-rumours-of-tension-8963506/, accessed 20 July 2022.

784 - *NEI Magazine*, "Czech company to support Egyptian regulator in licensing El-Dabaa", 29 November 2021, see https://www.neimagazine.com/news/newsczech-company-to-support-egyptian-regulator-in-licensing-el-dabaa-9284649/, accessed 29 July 2022.

785 - *Al-Monitor*, "Egypt licenses first power unit at Dabaa nuclear power plant", 6 July 2022, see https://www.al-monitor.com/originals/2022/07/egypt-licenses-first-power-unit-dabaa-nuclear-power-plant, accessed 18 August 2022.

Yet, the political will to move forward appears intact as both countries have reaffirmed their commitment to the project and its timeline on numerous occasions. In fact, on the day following the Russian invasion of Ukraine on 24 February 2022, Egyptian ministerial sources were quoted as saying work on-site was going on "as usual", and on 3 March 2022, the Egyptian Minister of Electricity and Renewable Energy expressed his confidence that the project would suffer no disruption.[786]

On 9 March 2022, Presidents El-Sisi and Putin discussed the implementation of joint nuclear projects during a phone-call.[787] On 3 April 2022, NPPA republished quotes from a TV-interview with the head of Rosatom, indicating that all construction projects the company was leading abroad were maintained, and the state company was currently assessing potential risks caused by the reconfiguration of global logistics.[788] In late May–early June 2022, a delegation of NPPA and ENRRA officials went on an official visit to Russia, to attend a ceremony celebrating the manufacturing of the reactor vessel in presence of their Rosatom counterparts.[789]

Beyond the eagerness of both parties to display their continuous cooperation, the joint efforts attained some significant milestones since the beginning of the invasion. Four days after the attack on Ukraine started, ENRRA granted the site permit for the spent fuel storage facility on site,[790] Rosatom secured a construction permit for Unit 1 on 29 June 2022,[791] and on 20 July 2022, construction was officially launched.[792] Meanwhile, the license applications for the remaining three units are still pending.

As previously mentioned, the likelihood of the project suffering impacts from sanctions following the war on Ukraine remains high, despite reassuring statements like former NPPA Deputy Head Ali Abdel Nabi indicating that "The sanctions on Moscow will not affect the course of the project because months ago [the Russian side] began manufacturing equipment for the nuclear plant, such as the reactor core catcher for nuclear units".[793] The bombing and near-destruction by Russia of a Rosatom-subsidiary Atomenergomash plant that manufactures key components like steam generator forgings for Rosatom's export projects (including

786 - *Al-Monitor*, "Ukraine war could delay Egypt's first nuclear power plant", 28 April 2022, see https://www.al-monitor.com/originals/2022/03/ukraine-war-could-delay-egypts-first-nuclear-power-plant, accessed 20 July 2022.

787 - Kremlin, "Telephone conversation with President of Egypt Abdel Fattah el-Sisi", Press Release, Government of Russia, 9 March 2022, see http://en.kremlin.ru/catalog/countries/EG/events/67952/print; and Russian Ministry of Foreign Affairs, Tweet, 9 March 2022, see https://twitter.com/Russia_AR/status/1501554758972317702; both accessed 30 July 2022

788 - *Regnum News Agency*, "Rosatom confirms construction of nuclear power plant projects abroad to continue", translated to English and published by NPPA, 3 April 2022, see https://nppa.gov.eg/en/rosatom-confirms-construction-of-nuclear-power-plant-projects-abroad-to-continue/, accessed 31 July 2022.

789 - NPPA, "NPPA Chairman is on an Official Visit to the Russian Federation, as a Head of a High-Level Egyptian Delegation to Attend the Ceremony to Start Manufacturing the Nuclear Reactor Vessel", Press Release, 1 June 2022, see https://nppa.gov.eg/en/nppa-chairman-is-on-an-official-visit-to-the-russian-federation-as-a-head-of-a-high-level-egyptian-delegation-to-attend-the-ceremony-to-start-manufacturing-the-nuclear-reactor-vessel/; and *NEI Magazine*, "Production of equipment begins for Egypt's El-Dabaa NPP", 3 June 2022, see https://www.neimagazine.com/news/newsproduction-of-equipment-begins-for-egypts-el-dabaa-npp-9748395/; both accessed 20 July 2022.

790 - NPPA, "NPPA obtained the site permit for the spent nuclear fuel storage facility", 3 March 2022, see https://nppa.gov.eg/en/nppa-obtained-the-site-permit-for-the-spent-nuclear-fuel-storage-facility/, accessed 14 July 2022.

791 - Rosatom ASE, "Construction Permit Issued for the El-Dabaa NPP Unit 1", Press Release, 30 June 2022 see https://ase-ec.ru/en/for-journalists/news/2009/jun/construction-permit-issued-for-the-el-dabaa-npp-unit-1/, accessed 1 July 2022.

792 - *WNN*, "Construction of Egypt's First Nuclear Power Plant Under Way", 20 July 2022, see https://world-nuclear-news.org/Articles/Construction-of-Egypts-first-nuclear-power-plant-u, accessed 20 July 2022.

793 - *Al-Monitor*, "Egypt, Russia discuss next steps for nuclear power plant", 28 April 2022, see https://www.al-monitor.com/originals/2022/04/egypt-russia-discuss-next-steps-nuclear-power-plant, accessed 20 July 2022.

El-Dabaa) in May 2022 offers a blunt example of a different kind of potential, yet unpredictable, disruption in the supply chain: Russia destroying its own assets in Ukraine.[794]

Questions have been raised as to whether ENRRA, established by law in 2010 and formed in 2012, has the capacity and political independence to effectively oversee the project.[795] Additionally, while Egyptian officials estimate that the project will bring the country US$246 billion in revenues over 60 years, some experts have raised concerns that the project will lead to a substantial increase in Egypt's foreign debt.[796] The NGO Egyptian Initiative for Personal Rights also criticized that "the process of public participation (...) was not satisfactorily done".[797] For example, the latest IAEA assessment of Egypt's regulatory competence, the Integrated Nuclear Infrastructure Review (INIR), was completed and handed over to the government on 24 September 2020,[798] but was not made public until much later.[799]

From a nuclear security perspective, Egypt's nuclear program poses several challenges. In 2018 independent experts have stressed that in recent years, "the rate, impact and sophistication of jihadi attacks in Egypt increased significantly and it is not unthinkable for Egypt's nuclear facilities to be targeted".[800]

The Government's Sustainable Development Strategy (SDS) "Egypt Vision 2030" developed in alignment with the UN's Sustainable Development Goals and launched in 2016 indicates that by 2030, 9 percent of the country's electricity generation would be covered by nuclear power, but does not mention any further projects than that of El-Dabaa.[801] It has been known since January 2021 that an updated version of "Egypt Vision 2030" was in the making,[802] and in July 2021 NPPA executive, Husham Hegazy, revealed during a panel discussion that Egypt plans to build "several" other reactors "in various regions" to provide at least 8 percent of the country's electricity from nuclear power by 2030.[803] According to *Al-Monitor*, NPPA refused to provide further details following Husham Hegazy's comments, saying that "such information

794 - Phil Chaffee, "Russians Shell Rosatom-Owned Manufacturing Plant", *Nuclear Intelligence Weekly*, 6 May 2022.

795 - Egyptian Initiative for Personal Rights, "EIPR objects to nuclear energy laws and demands that nuclear plant contracts not be signed before laws are reviewed", Press Release, 10 December 2017, see https://www.eipr.org/en/press/2017/12/eipr-objects-nuclear-energy-laws, accessed 20 July 2022.

796 - Warsaw Institute, "Russia Kicks Off Work On Egypt's First Nuclear Power Plant", 26 February 2020, see https://warsawinstitute.org/russia-kicks-off-work-egypts-first-nuclear-power-plant/, accessed 17 July 2021.

797 - Egyptian Initiative for Personal Rights, "'Without guarantees' A study on nuclear energy and the Dabaa project", 21 November 2019, see https://eipr.org/en/publications/without-guarantees-el-dabaa-nuclear-energy-project, accessed 17 July 2021.

798 - IAEA, "IAEA Delivers INIR Mission Reports to Belarus and Egypt", 24 September 2020, see https://www.iaea.org/newscenter/news/iaea-delivers-inir-mission-reports-to-belarus-and-egypt, accessed 17 July 2021.

799 - IAEA, "Mission Report on the Integrated Nuclear Infrastrucutre Review (INIR) – Phase 2", 27 October – 6 November 2019, see https://www.iaea.org/node/56676, accessed 29 July 2022.

800 - Kareem Gerges and Ali Ahmad, "Egypt's Nuclear Power Program: Security and Economic Risks", Policy Brief #6/2018, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, October 2018, see https://www.aub.edu.lb/ifi/Documents/publications/policy_briefs/2018-2019/20181018_egypt_nuclear_power_program.pdf, accessed 17 July 2021.

801 - Government of Egypt, "Egypt Vision 2030", 2016, see http://www.cairo.gov.eg/en/GovernorsCVs/sds_egypt_vision_2030.pdf, accessed 14 July 2022.

802 - *Egypt Today*, "Egypt's Vision 2030 updated in line with changes ensued from COVID-19, success achieved until present", 11 January 2021, see https://www.egypttoday.com/Article/3/96293/Egypt-s-Vision-2030-updated-in-line-with-changes-ensued, accessed 1 August 2022.

803 - Darrell Proctor, "El Dabaa First of 'Several' Nuclear Reactors for Egypt", *POWER*, 15 July 2021, see https://www.powermag.com/el-dabaa-first-of-several-nuclear-reactors-for-egypt/, accessed 14 July 2022.

will only be revealed when the time is right".[804] As of July 2022, the time apparently is not right yet. However, considering the known long lead and construction times, likely no electricity will be generated by any nuclear power plant in Egypt by 2030.

The country's revised NDC report released in early June 2022, still mentions the "2035 Integrated Sustainable Energy Strategy" established in 2016 as reference on its renewable energy targets, and forecasts that by 2030 renewables will make up 40 percent of installed capacity.[805] In parallel, the Egyptian Government has launched a series of energy reforms such as a feed-in-tariff that incentivized private sector to get involved in the country's electricity sector, providing new financing pathways.[806]

Egypt is also making strides in the development of a domestic and regional natural gas market. Besides being host to Zohr, the largest gas field in the Eastern Mediterranean,[807] Egypt has invested in gas import and export infrastructure to position itself as regional hub, and in the process, become self-sufficient. (See WNISR2020 – Middle East Focus). These developments will have a great impact on Egypt's electricity supply security as well as the future steps the country may take in shaping its energy policy.

Nigeria

In Nigeria, 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.[808] 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.[809]

A conference organized in July 2022 by the Heinrich Böll Foundation and the Electricity Hub in Abuja, Nigeria,[810] saw the former Chairman of the Nigerian Electricity Regulatory Commission (NERC) pointing to the lack of adequate transmission infrastructure to receive

804 - Hagar Hosny, "Egypt plans to build more nuclear power stations", *Al-Monitor*, July 2021, see https://www.al-monitor.com/originals/2021/07/egypt-plans-build-more-nuclear-power-stations, accessed 20 July 2022.

805 - Government of Egypt, "Egypt's First Updated Nationally Determined Contributions", 8 June 2022, see https://unfccc.int/sites/default/files/NDC/2022-07/Egypt%20Updated%20NDC.pdf.pdf, accessed 20 July 2022.

806 - Oxford Business Group, "Egypt's energy sector undergoes reforms to regulations, energy mix", 19 March 2017, see https://oxfordbusinessgroup.com/analysis/composition-makeover-sector-undergoing-reforms-regulations-and-energy-mix, accessed 29 July 2021.

807 - Ehab Farouk and Yousef Saba, "UPDATE 1-Egypt's Zohr gas field output rises to 2.7 bln cubic feet per day - minister", *Reuters*, 21 August 2019, see https://www.reuters.com/article/egypt-energy-idAFL5N25H1VW, accessed 17 July 2021.

808 - *WNN*, "Nigerian Senate calls for inclusion of nuclear in energy mix", 21 November 2019, see https://www.world-nuclear-news.org/Articles/Senate-calls-for-nuclear-inclusion-in-Nigeria-s-en, accessed 1 May 2021.

809 - *WNN*, "Nigeria moving ahead on nuclear power plant plan", 18 March 2022, see https://www.world-nuclear-news.org/Articles/Nigeria-moving-ahead-on%C2%A0nuclear-power-plant-plan, accessed 18 March 2022.

810 - The WNISR-Coordinator gave a presentation at the event.

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".[811]

In continental Africa, only South Africa has an operating nuclear power plant (see section on South Africa in Annex 1). This is despite sporadic support from national governments and encouragement from international vendors, more recently particularly China and Russia.

Across the continent, electricity generation increased from 672 TWh in 2010 to just under 900 TWh in 2021, with nuclear providing 1.2 percent in 2021. Africa does however have a significant role for the global nuclear industry with Namibia and Niger being the world's fourth- and fifth-largest uranium producers.

According to the World Nuclear Association (WNA), China has agreements with—but no plants under construction—Kenya, Sudan, and Uganda, while Russia signed agreements with Algeria, Congo, Egypt, Ethiopia, Ghana, Morocco, Nigeria, Sudan, Rwanda, Tunisia, and Zambia.[812]

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.[813] The vast majority of these are little more than political statements of support designed to increase diplomatic links with key infrastructure providers and recipients.

Rwanda in October 2019 signed an agreement with Rosatom to build a nuclear science center with the intention of developing an interest in Small Modular Reactors (SMRs).[814]

Few developments on nuclear activities in Africa reflect some significance on the ground.

Poland

Poland planned the development of a series of 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. Since then, there has been a long, expensive, and time-consuming series of attempts to restart the nuclear program. In 2008, Poland announced that it was going to re-enter the nuclear arena and in November 2010, the Ministry of Economy put forward a Nuclear Energy Program. On 28 January 2014, the Polish Government adopted a document with the title "Polish Nuclear Power Programme" outlining the framework of the strategy. The plan included proposals to

811 - *The Autority*, "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.

812 - WNA, "Emerging Nuclear Energy Countries", Updated May 2022, see https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx, accessed 24 August 2022.

813 - *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.

814 - Katya Golubkova and Alexander Winning, "Russia's Rosatom, Rwanda sign deal to build nuclear science center", *Reuters*, 24 October 2019, see https://www.reuters.com/article/us-russia-rwanda-nuclear-idUSKBN1X32DV, accessed 1 May 2021.

build 6 GW of nuclear power capacity with the first reactor starting up by 2024. The reactor types then under consideration included AREVA's EPR, Westinghouse's AP1000, and Hitachi-GE's ABWR. Since then, AREVA went bankrupt and was broken up, while Westinghouse filed for bankruptcy protection and was sold to a Canadian holding, and Hitachi-GE has never completed an ABWR.

In January 2013, the Polish state-owned utility PGE (Polska Grupa Energetyczna) selected WorleyParsons to conduct a five-year, US$81.5 million study, on the siting and development of a nuclear power plant with a capacity of up to 3 GW. At that time, the project was estimated at US$13–19 billion and construction was to begin in 2019. In January 2014, PGE received four bids from companies looking to become the company's "Owner's Engineer" to help in the tendering and development of the project, which was eventually awarded to AMEC Nuclear U.K. in July 2014. The timetable demanded that PGE make a final investment decision on the two plants by early 2017.[815] That did not happen.

In November 2018, the Government published a draft strategic energy development program, which called for the construction of four reactors (providing 6–10 GW of capacity) by 2040, with the first in operation by 2033[816] and up to six units with a combined capacity of 6–9 GW to be put into operation by 2043.[817] The Ministry of Energy envisaged the site selection for the first plant in 2020, while the technology would be chosen in 2021.[818]

In October 2020, the Council of Ministers adopted the government's long-term Polish Nuclear Power Program. Its main objective is 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 energy mix of 2045 is predicted to be about 20 percent. According to the documentation, the timetable for the first plan (EJ1) is as follows:

- 2021: choice of technology;
- 2022: environmental and location decision;
- 2026: a building permit is obtained and construction commenced;
- 2033–2037: an operating permit is issued by the President of the National Atomic Energy Agency and three nuclear power plant units are commissioned (EJ1).[819]

In late December 2021, Polskie Elektrownie Jadrowe (PEJ), a public company set up to develop the Polish nuclear program, announced it had chosen the village of Choczewo in Pomerania

815 - David Dalton, "Amec Wins USD 430 Million Contract To Support Polish New-Build", *Nucnet*, 9 July 2014, see https://www.nucnet.org/all-the-news/2014/07/21/amec-wins-usd-430-million-contract-to-support-polish-new-build, accessed 1 May 2021.

816 - Gary Peach, "Newbuild: Power Demand in Poland Bolsters Case for Nuclear", *Nuclear Intelligence Weekly*, 26 November 2018.

817 - *WNN*, "Poland sets financing target for nuclear plant", 19 November 2019, see https://www.world-nuclear-news.org/Articles/Poland-sets-financing-target-for-nuclear-plant, accessed 1 May 2021.

818 - *WNN*, "Poland already preparing for nuclear plant, says energy minister", 16 May 2019, see https://www.world-nuclear-news.org/Articles/Poland-already-preparing-for-nuclear-plant,-says-e, accessed 1 May 2021.

819 - *CMS Law-Now*, "The 2020 Polish Nuclear Power Programme – main objectives", 26 October 2020, see https://www.cms-lawnow.com/ealerts/2020/10/the-2020-polish-nuclear-power-programme-main-objectives, accessed 1 May 2021.

for the first reactor.[820] In March 2022, PEJ submitted the Environmental Impact Assessment report for the project.[821]

As of mid-September 2022, the technology had not been selected. France's EDF is still offering its EPR, the US' Westinghouse keeps promoting the AP1000[822], South Korea's KHNP has reportedly submitted an offer for six APR-1400, and Japan hopes to finally sell an ABWR.[823] In May 2022, a Polish official was quoted as expecting a decision about the technology "in the fall".[824]

In October 2021, EDF submitted a non-binding offer for four to six EPRs with 6.6–9.9 GW at overnight costs (excluding financing) of €33–48.5 billion (US$38–56 billion). EDF said, it was "open to discussions with the Polish government on the question of who and what kind of financing will be provided. How the financing structure and its division among shareholders will look needs further talks."[825] In other words, the negotiations are far from a provider/technology selection and financing solution.

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 the 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."[826] It remains unclear whether the offer to inject capital would cover the first two units only or the entire package of up to six APR-1400. In any case, the Korean initiative represents a financing offer that could not be matched by cash strapped EDF or Westinghouse that is currently up for sale.

In addition to negotiations around potential large reactor orders, Poland eyes the possibility of 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 Last Energy to cooperate on the deployment of SMRs.[827]

Meanwhile, solar photovoltaics reached 10 GW installed capacity in May 2022, a tenfold increase in just three years, with the objective of reaching 28.5 GW by 2030.[828]

820 - *NEI Magazine*, "Poland selects site for first nuclear power plant", *Nuclear Engineering International*, 30 December 2021, see https://www.neimagazine.com/news/newspoland-selects-site-for-first-nuclear-power-plant-9354373, accessed 31 August 2022.

821 - PEJ, "Polskie Elektrownie Jądrowe Sp. z o. o. submits the Environmental Impact Assessment Report for the First Nuclear Power Plant in Poland", Press Release, Polskie Elektrownie Jądrowe, 31 March 2022, see https://pgeej1.pl/en/news/polskie-elektrownie-jadrowe-sp-z-o-o-submits-the-environmental-impact-assessment-report-for-the-first-nuclear-power-plant-in-poland, accessed 19 September 2022.

822 - *NEI Magazine*, "Westinghouse seeks participation in Poland's nuclear programme", *Nuclear Engineering International*, 18 March 2021, see https://www.neimagazine.com/news/newswestinghouse-seeks-participation-in-polands-nuclear-programme-8609350, accessed 1 May 2021.

823 - Daishi Chiba, "Poland minister seeks Japanese partners for nuclear project", *Nikkei Asia*, 3 December 2021, see https://asia.nikkei.com/Editor-s-Picks/Interview/Poland-minister-seeks-Japanese-partners-for-nuclear-project, accessed 1 May 2021.

824 - *NIW*, "Weekly Roundup", *Nuclear Intelligence Weekly*, 10 June 2022.

825 - *Platts Nuclear News Flashes*, "EDF considering financing models for project to build EPRs in Poland", 29 June 2022.

826 - Phil Chaffee, "KHNP Jolts Competitors With Equity Stake Appetite", *Nuclear Intelligence Weekly*, 3 June 2022.

827 - *WNN*, "Poland expands cooperation on SMRs and large reactors", 23 June 2022, see https://www.world-nuclear-news.org/Articles/Poland-expands-cooperation-on-SMRs-and-large-react, accessed 23 June 2022.

828 - *Bankier.pl*, "Ministerstwo Klimatu: w maju łączna moc w fotowoltaice przekroczyła 10 GW. Polska na 7. miejscu w Europie" ["Ministry of Climate: total photovoltaic capacity exceeded 10 GW in May. Poland in 7th place in Europe"], 25 May 2022 (in Polish), see https://www.bankier.pl/wiadomosc/Ministerstwo-Klimatu-w-maju-laczna-moc-w-fotowoltaice-przekroczyla-10-GW-Polska-na-7-miejscu-w-Europie-8344499.html, accessed 24 August 2022.

Saudi Arabia

The King Abdullah City for Atomic and Renewable Energy (KA-CARE), a research entity headed by the Minister of Energy, Industry and Mineral Resources, was established by a Royal Decree in 2010.[829] In November 2013, an official KA-CARE spokesperson announced that it would be calling for preliminary bids the following year, with the first nuclear reactor to start construction in 2017 and be completed in 2022; the reactor would be part of a decade-long plan to construct 18 GW of nuclear power capacity.[830] There has been no nuclear power plant construction so far.

In the past decade, KA-CARE has signed several agreements with countries like Argentina,[831] China,[832] France,[833] Hungary,[834] Russia,[835] and South Korea.[836] These agreements form part of a pattern of traditional nuclear supplier states competing intensely for rare orders in the Middle East.[837] Some of these agreements revolve around Small Modular Reactor (SMR) designs, in particular South Korea's SMART and China's High Temperature Gas-Cooled Reactor designs (see earlier WNISR editions).

In 2021, KA-CARE called for bids from companies seeking to play "the transaction advisory role on the kingdom's first planned large-scale nuclear power project" and in May 2022, KA-CARE picked the U.K.'s Ernst & Young (EY); other companies that have been similarly selected by KA-CARE in the past include France's Assystem "to conduct a site characterisation study, environmental impact assessment and preliminary safety analysis" and Australia's WorleyParsons to "provide consultancy services including: project governance, resource

829 - Abdullah bin Abdul Aziz Al Saud, "Royal Decree establishing King Abdullah City for Atomic and Renewable Energy 2010", April 2010, see https://www.climate-laws.org/geographies/saudi-arabia/policies/royal-decree-establishing-king-abdullah-city-for-atomic-and-renewable-energy-2010, accessed 10 June 2021.

830 - 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 15 November 2013.

831 - Government of the Argentine Republic and Government of the Kingdom of Saudi Arabia "Cooperation Agreement Between the Government of the Argentine Republic and the Government of the Kingdom of Saudi Arabia on Peaceful Uses of Nuclear Energy", 28 June 2011, Registration with the Secretariat of the UN 6 November 2013, Volume 2963, No.51496, United Nations, 2011, see https://www.un-ilibrary.org/content/books/9789210453349s002-c006, accessed 13 July 2021.

832 - *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.

833 - *WNN*, "Areva, EDF team up with Saudis", 6 January 2014, see https://world-nuclear-news.org/Articles/Areva,-EDF-team-up-with-Saudis, accessed 2 June 2021.

834 - KA-CARE, "The Kingdom of Saudi Arabia concludes a cooperation agreement with Hungary on the peaceful uses of atomic energy", 2015, see https://www.energy.gov.sa/en/mediacenter/news/Pages/news177.aspx, accessed 13 July 2021.

835 - KA-CARE, "Saudi Arabia sign an idolater cooperation agreement in the areas of peaceful nuclear energy with the Federal Republic of Russia", 2015, see https://www.energy.gov.sa/en/mediacenter/news/Pages/news156.aspx, accessed 13 July 2021; and *WNN*, "Russia, Saudi Arabia strengthen ties in nuclear energy", 6 October 2017, see https://world-nuclear-news.org/Articles/Russia,-Saudi-Arabia-strengthen-ties-in-nuclear-en, accessed 30 May 2021.

836 - *WNN*, "Saudi Arabia teams up with Korea on SMART", 4 March 2015, see https://www.world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html, accessed 14 May 2020; and *WNN*, "Saudi Arabia and Korea further SMART cooperation", 3 September 2015, see https://world-nuclear-news.org/Articles/Saudi-Arabia-and-Korea-further-SMART-cooperation, accessed 28 May 2021; also Jane Chung, "South Korea's KEPCO shortlisted to bid for Saudi nuclear project", *Reuters*, 1 July 2018, see https://www.reuters.com/article/us-southkorea-nuclear-saudi/south-koreas-kepco-shortlisted-to-bid-for-saudi-nuclear-project-idUSKBN1JR1GA, accessed 1 July 2018; and *WNN*, "Korea, Saudi Arabia to cooperate on SMART deployment", 20 September 2019, see https://world-nuclear-news.org/Articles/Korea,-Saudi-Arabia-to-cooperate-on-SMART-deployme, accessed 3 June 2021; and Phil Chaffee, "Smart SMR Cements Saudi-Korean Partnership", *Nuclear Intelligence Weekly*, 10 July 2020.

837 - M. V. Ramana and Zia Mian, "Scrambling to sell a nuclear Middle East", *Bulletin of the Atomic Scientists*, Vol 72, Issue 1, 8 January 2016.

management, project services, training and compliance across the full scope of the large nuclear power plant (LNPP), small modular reactors and nuclear fuel cycle”.[838]

In May 2022, KA-CARE invited bids from China, France, Russia, and South Korea to construct two 1,400 MW nuclear reactors.[839] The indicated capacity is close to that of South Korea’s APR1400 design and South Korea’s new President Yoon Suk-yeol and his government are “expected to make all-out efforts to win the nuclear reactor order, which would be its first nuclear plant deal in over a decade”.[840]

One constraint is that to export the APR1400, South Korea requires permission from the United States, which holds intellectual property rights over some components of the APR1400.[841] The hope on the part of South Korean nuclear officials is that they might be allowed to proceed with a contract on the “condition that U.S. companies such as Westinghouse supply components and share the proceeds of the project”.[842] In the case of Barakah in the UAE, about 10 percent of the total project proceeds went to U.S. companies.

Saudi Arabia’s renewable energy capacity has grown over the past 10 years from 14 MW in 2012 to 443 MW in 2021, of which solar power constitutes 439 MW.[843] Yet, for a country that is blessed with sunshine and wind resources, renewable energy contributes only a modest share of 0.6 percent of the total electricity generation capacity of the kingdom, and 0.23 percent of electricity generated in 2021.[844] However, last year, deals have been signed that could deliver a combined capacity of 3.7 GW, with one power purchase agreement being struck at the record low value of US$10.4 per MWh.[845]

Turkey

Turkey is in the process of building its first nuclear power plant at Akkuyu in the province of Mersin on the Mediterranean coast. The plant is being built by Russia’s Rosatom using a BBO (build-own-operate) financing model and involves four VVER-1200 reactors[846], with a

838 - *Energy and Utilities*, “Adviser appointed for Saudi nuclear power programme”, 25 May 2022, see https://energy-utilities.com/adviser-appointed-for-saudi-nuclear-power-news117665.html, accessed 26 July 2022.

839 - 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.

840 - Zi-Hoon Lee and So-Hyeon Kim, “S.Korea to bid for Saudi Arabia’s $10 bn nuclear plant order”, *KED Global*, 31 May 2022, see https://www.kedglobal.com/energy/newsView/ked202205310016, accessed 3 June 2022.

841 - François Lévêque and Michel Berthélemy, “Korea nuclear exports: Why did the Koreans win the UAE tender? Will Korea achieve its goal of exporting 80 nuclear reactors by 2030?”, CERNA Working Paper Series, Centre d’économie industrielle, Mines ParisTech, April 2010, see https://inis.iaea.org/collection/NCLCollectionStore/_Public/43/035/43035079.pdf, accessed 18 August 2022.

842 - Jung Suk-yee, “Nuclear Power Plant Project Anticipated in Saudi Arabia”, *Business Korea*, 2 June 2022, op. cit.

843 - IRENA, “Renewable Capacity Statistics 2022”, International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

844 - BP, “Statistical Review of World Energy 2022”, June 2022, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 12 July 2022.

845 - Igor Todorović, “Saudi Arabia to add 3.7 GW in solar power, achieves world’s lowest price”, *Balkan Green Energy News*, 13 April 2021, see https://balkangreenenergynews.com/saudi-arabia-to-add-3-7-gw-in-solar-power-achieves-worlds-lowest-price/, accessed 13 July 2021; and Sophie Vorrath, “Saudi solar plant locks in new record low price for power: 1.04c/kWh”, *RenewEconomy*, 13 April 2021, see https://reneweconomy.com.au/saudi-solar-plant-locks-in-new-record-low-price-for-power-1-04c-kwh/, accessed 9 July 2021.

846 - As of 1 July 2022, three reactors were under construction. Construction start of Unit 4 was announced on 21 July 2022.

total capacity of 4,800 MW.[847] Two other proposed nuclear projects, Sinop and İğneada, have not moved forward.

Akkuyu was selected in 1976 to host a nuclear power plant, in the second of six attempts to introduce nuclear power to Turkey.[848] But it was only in 2010 that then Russian President Dmitry Medvedev and Turkey's Prime Minister Recep Tayyip Erdoğan signed the deal, estimated at US$20 billion, that was to set the stage for the current project.[849] At that time, the four reactors were expected to become operational "between 2016 and 2019".[850] But, as detailed in previous editions of the WNISR, there have been several delays, and construction of the first unit began only in 2018.[851] The other three units began construction in April 2020, March 2021, and July 2022.[852]

In 2018, just prior to the start of construction of the first unit, a Turkish consortium that was to have provided 49 percent of the funding for the plant, pulled out of the project.[853] Rosatom has reportedly received loans worth US$1.2 billion from Sberbank and loans valued at likely a similar amount from Sovcombank; both banks have been hit by sanctions since Russia's invasion of Ukraine.[854] To alleviate concerns about these sanctions, Rosatom stated that it was transferring billions of dollars to Akkuyu Nuclear, Rosatom's subsidiary that is building the reactors, including US$5 billion in July 2022.[855]

Then, also in July 2022, Akkuyu Nuclear terminated its agreement with IC Içtaş, a Turkish construction company, and signed an engineering, procurement and construction contract with a company called TSM Enerji, owned by three Russia-based companies.[856] Rosatom justified the decision by stating "IC Ictas committed numerous violations affecting the quality and timing

847 - IEA, "Turkey 2021 - Energy Policy Review", International Energy Agency, March 2021, see https://www.iea.org/reports/turkey-2021, accessed 24 July 2022.

848 - Y. Bektur and U. Bezdegumeli, "Nuclear Power Plant Attempts in Turkey and the First Licensed Site", in Proceedings of the Third Eurasian Conference "Nuclear Science and its Application", 5 October 2004, see https://inis.iaea.org/collection/NCLCollectionStore/_Public/38/111/38111303.pdf, accessed 29 September 2020. See also, Avino Niphi and M. V. Ramana, "Talking points: Narrative strategies to promote nuclear power in Turkey", in *Energy Democracies for Sustainable Futures*, Forthcoming, see https://www.elsevier.com/books/energy-democracies-for-sustainable-futures/nadesan/978-0-12-822796-1, accessed 20 August 2022.

849 - *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.

850 - Ibidem.

851 - *WNN*, "Russia starts building Turkey's first nuclear power plant", 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.

852 - *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; also 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/, accessed 11 March 2021; and Akkuyu Nükleer A.Ş., "Main Construction Phase Commences at Akkuyu NPP Unit 4 in Turkey", Akkuyu Nuclear, Rosatom, Press Release, 21 July 2022, see http://www.akkuyu.com/main-construction-phase-commences-at-akkuyu-npp-unit-4-in-turkey/update, accessed 21 July 2022.

853 - Charles Digges, "Investor pullout leaves Rosatom at sea with its nuclear project in Turkey", Bellona, 12 February 2018, see http://bellona.org/news/nuclear-issues/2018-02-investor-pullout-leaves-rosatom-at-sea-with-its-nuclear-project-in-turkey, accessed 30 April 2018.

854 - Andrew Wilks, "Turkish nuclear plant threatened by Russian sanctions", *Al Jazeera*, 16 May 2022, see https://www.aljazeera.com/news/2022/5/16/turkish-nuclear-plant-threatened-by-russian-sanctions, accessed 25 July 2022.

855 - Firat Kozok, "Russia Is Wiring Dollars to Turkey for $20 Billion Nuclear Plant", *Bloomberg*, 29 July 2022, see https://www.bloomberg.com/news/articles/2022-07-29/russia-is-wiring-dollars-to-turkey-for-20-billion-nuclear-plant, accessed 3 August 2022.

856 - *Daily Sabah*, "Russia signs new construction deal for Turkey's 1st nuclear plant", 31 July 2022, see https://www.dailysabah.com/business/energy/russia-signs-new-construction-deal-for-turkeys-1st-nuclear-plant, accessed 3 August 2022.

of work".[857] IC Içtaş accused Rosatom of trying to "reduce Turkish corporate presence" on the Akkuyu project. Turkey's Ministry of Energy and Natural Resources is attempting to solve the dispute between the involved parties.[858]

Startup of Akkuyu-1 is expected in 2023, to coincide with the 100th anniversary of the foundation of the Republic of Turkey –as well as the general election– but as early as 2019, risks of delays have been expressed, due to technical or organizational issues, and WNISR uses a 2024 expected grid connection date for Unit 1, to be followed by one unit per year.

Meanwhile, in June 2022, the 35th Council of the European Green Parties passed a resolution requesting to scrap the Akkuyu project citing concerns over earthquake risks, as Akkuyu "sits on a major plate tectonic fault line". The statement also asserts: "Within the perspective of the adequate use of renewable sources' energy potential, Turkey does not need to rely on nuclear power."[859]

Over the past decade, installed capacity of renewables in Turkey has grown from 22 GW in 2012 to 53.2 GW in 2021, with 31.5 GW hydropower, 10.6 GW from wind energy (up from 2.3 GW in 2012), 7.8 GW from solar energy (12 MW in 2012), 1.6 GW from bioenergy, and 1.7 GW from geothermal energy (162 MW in 2012).[860] Together these constituted 53.3 percent of Turkey's electricity generation capacity in 2021. In terms of actual production, renewables generated about 19 percent of Turkey's electrical energy in 2021 of which about 17 percent came from hydropower.[861]

SUSPENDED OR CANCELLED PROGRAMS

Indonesia

Indonesia is ranked sixteenth in terms of GDP and in 2021 was one in four countries in the Top 20[862] besides Australia, Italy (that phased out its 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)

857 - *NEI Magazine*, "Rosatom gives more details of construction dispute at Akkuyu NPP", 12 August 2022, see https://www.neimagazine.com/news/newsrosatom-gives-more-details-of-construction-dispute-at-akkuyu-npp-9924509, accessed 12 August 2022.

858 - *Daily Sabah*, "Turkey seeks to resolve row over Russian-built $20B nuclear plant", 3 August 2022, see https://www.dailysabah.com/business/economy/turkey-seeks-to-resolve-row-over-russian-built-20b-nuclear-plant, accessed 5 August 2022.

859 - European Greens, "Adopted Resolution—Stop the Akkuyu Nuclear Plant", June 2022.

860 - IRENA, "Renewable Capacity Statistics 2022", International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

861 - BP, "Statistical Review of World Energy 2022", June 2022, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 12 July 2022.

862 - World Development Indicators Database, "Gross Domestic Product 2021", World Bank, 1 July 2022, see https://databank.worldbank.org/data/download/GDP.pdf, accessed 22 August 2022.

for either power generation or marine vehicle propulsion.[863] 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 remains a top producer in 2022.[864]

According to local media, the government has prepared a draft law on "new and renewable energies" that would create a framework also for the development of nuclear energy. In its June 2022 version, the draft text reportedly stipulates that only state-owned companies would be allowed to build and operate nuclear power plants, a condition that would be fatal to the Thorcon project that hoped for construction to begin by 2024–2025. Current 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 and envision a first unit to begin operation in 2045,[865] leaving much room for uncertainty on the future developments of these projects, the first question being whether the parliament will indeed approve the bill.

Jordan

Jordan has been seeking to develop the capacity to generate nuclear energy for about a decade and a half. The interest in nuclear power is rather surprising in what is one of the water-poorest countries in the world, as nuclear is the most water-intensive technology to generate electricity.

After it was established in 2008,[866] the Jordan Atomic Energy Commission (JAEC) has explored the development of a nuclear power plant. One option was importing two 1,000 MW nuclear reactors from Russia,[867] but the agreement was formally cancelled reportedly because of funding challenges.[868] A second option that JAEC explored was to obtain a High Temperature Reactor (HTR) from the China National Nuclear Corporation (CNNC).[869] To date, Jordan remains far from being able to start construction of any reactor. It only operates a small (5 MWth) research and training reactor imported from South Korea.[870]

863 - *NEI Magazine*, "Indonesia signs MOU on molten salt reactor", 31 July 2021, see https://www.neimagazine.com/news/newsindonesia-signs-mou-on-molten-salt-reactor-8055819/, accessed 1 May 2021.

864 - 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.

865 - Marc Roussot, "Southeast Asia Rethinks Nuclear Energy", *Nuclear Intelligence Weekly*, 24 June 2022.

866 - JAEC, "Jordan Atomic Energy Commission—About Us", Jordan Atomic Energy Commission, Undated, see http://www.jaec.gov.jo/Pages/viewpage?pageID=1, accessed 1 May 2021.

867 - Rosatom, "Russia and Jordan signed Project Development Agreement on Nuclear Power Plant Construction", Press Release, 22 September 2014; *WNN*, "Jordan, Russia sign project development agreement", 23 September 2014, see https://www.world-nuclear-news.org/Articles/Jordan,-Russia-sign-project-development-agreement, accessed 22 May 2021; *AP*, "Russia to build Jordan's first nuclear power plant", as published on *Al Jazeera*, 24 March 2015, see https://www.aljazeera.com/news/2015/3/24/russia-to-build-jordans-first-nuclear-power-plant, accessed 3 May 2021.

868 - 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, accessed 5 July 2018.

869 - 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.

870 - *WNN*, "Jordan research reactor complete", 12 December 2016, see https://www.world-nuclear-news.org/Articles/Jordan-research-reactor-complete, accessed 4 May 2021.

JAEC did establish the Jordanian Uranium Mining Company (JUMCO) in 2013,[871] and it has been operating a pilot scale uranium processing plant since 2021.[872] Earlier in 2022, JUMCO announced that it had produced 20 kg of yellowcake from 160 tons of uranium ore.[873]

Jordan's total renewable energy generation capacity has grown from 17 MW in 2012 to 2.2 GW in 2021, with most of that latter figure coming from wind (622 MW) and solar (1.5 GW); renewable energy capacity constitutes 34 percent of installed power generation capacity in 2021, up from 0.5 percent in 2012.[874] This fraction is well beyond the initial target of 31 percent by 2030 from the Ministry of Energy and Mineral resources.[875] In 2021, the minister of energy and mineral resources announced that Jordan aims to expand the share of electricity from renewables to more than 50 percent by 2030 so as to strengthen the utilization of local energy sources.[876]

Kazakhstan

Kazakhstan operated a small fast breeder reactor, the BN350 at Aktau, between 1972–1998 and is one of three countries in the world to have abandoned commercial nuclear power, the others being 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. In April 2019, during a meeting between President Putin of Russia and Kazakhstan's President Qasym-Zhomart Toqaev, it was suggested that Russia 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.[877]

In January 2022, trade journal *Nuclear Intelligence Weekly* wondered: "Tokayev 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?"[878]

871 - JAEC, "Jordanian Uranium Project", Jordan Atomic Energy Commission, 2022, see https://jaec.gov.jo/Pages/viewpage?pageID=31, accessed 25 July 2022.

872 - *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.

873 - 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", 13 May 2022, see https://www.world-nuclear-news.org/Articles/Jordan-announces-uranium-production, accessed 14 May 2022.

874 - IRENA, "Renewable Capacity Statistics 2022", International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

875 - IRENA, "Renewables Readiness Assessment: The Hashemite Kingdom of Jordan", International Renewable Energy Agency, February 2021, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Feb/IRENA_RRA_Jordan_Summary_2021_EN.pdf?la=en&hash=DE5015E14770A43E9BFF2DFF8FAE684CED6E8EEB, accessed 1 May 2021.

876 - Anna Ivanova, "Jordan targets over 50% green electricity by 2030 - report", *Renewables Now*, 17 November 2021, see https://renewablesnow.com/news/jordan-targets-over-50-green-electricity-by-2030-report-761742/, accessed 10 August 2022.

877 - 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.

878 - *NIW*, "Kazakhstan – As Faultlines Exposed, Uranium Production Proceeds", *Nuclear Intelligence Weekly*, 14 January 2022.

The answer seems to be that the Government was evaluating other possibilities. In December 2021, KNPP signed a Memorandum of Understanding (MoU) with NuScale to explore the potential deployment of Small Modular Reactors (SMRs) in Kazakhstan,[879] and in late June 2022, a further MoU was signed with Korea Hydro & Nuclear Power (KHNP) to cooperate "in the field of nuclear energy development". Both companies had already submitted proposals to Kazakhstan in 2019.

In February 2022, it was reported that the government was considering six suppliers: 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 technology have not been implemented anywhere yet. KNPP is expected to submit a proposal by Q3 2022 for the construction of two new plants for a combined capacity of 2.8 GW.[880]

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.[881] The first unit is scheduled to start up in 2022.

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."[882] 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.

Uzbekistan

Uzbekistan has announced its intention to develop nuclear power, with the help of Russia. In an April 2019 interview with *Nuclear Engineering International* (*NEI*), Jurabek Mirzamakhmudov, Director General of Uzatom, announced site analysis work over the following 18 months at three locations. Mirzamakhmudov said that they have chosen the VVER-1200 reactor design, which would be financed through an engineering, procurement, and construction agreement

879 - NuScale, "NuScale Power Signs Memorandum of Understanding with KNPP to Explore SMR Deployment in Kazakhstan", Press Release, 16 December 2021, see https://newsroom.nuscalepower.com/press-releases/news-details/2021/NuScale-Power-Signs-Memorandum-of-Understanding-with-KNPP-to-Explore-SMR-Deployment-in-Kazakhstan/default.aspx, accessed 29 August 2022.

880 - *WNN*, "Kazakh, Korean companies to cooperate in nuclear power projects", 29 June 2022, see https://www.world-nuclear-news.org/Articles/Kazakh,-Korean-companies-to-cooperate-in-nuclear-p, accessed 29 August 2022.

881 - *NIW*, "Potential and Existing Conventional Nuclear Newbuild Projects (Generation III or Earlier) Currently Planned", 24 September 2021.

882 - *WNN*, "China, Thailand agree to nuclear energy cooperation", 5 April 2017, see https://www.world-nuclear-news.org/NP-China-Thailand-agree-to-nuclear-energy-cooperation-0504174.html, accessed 1 May 2021.

via 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.[883] It was later stated that the intention was to choose a site, and have it licensed by September 2020,[884] 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 would still be under negotiation, recent Ukraine-related sanctions against Russia would have no impact on the process. He added that one of the reasons of delay would be ongoing analysis whether to use "dry cooling" towers to save water uptake from Lake Tuzkan.[885]

A ten-year plan for electricity provision was developed with the Asian Development Bank (ADB) and the World Bank. It aims to deploy up to 30 GW of additional power capacity by 2030, including 5 GW of solar PV, 3.8 GW of hydropower, 2.4 GW of nuclear and up to 3 GW of wind energy.[886]

Vietnam

Vietnam, with its growing economy and energy demand, for decades had been seen a model country 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.[887] However, ambitions were severely curtailed in November 2016, when 92 percent of the 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, and rising construction costs.[888]

Despite this, a draft power plan published by the Ministry of Industry and Trade in July 2020 envisages building nuclear power plants with a capacity of 1 GW by 2040 and 5 GW by 2045.[889] 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

883 - *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.

884 - *WNN*, "Russia and Uzbekistan agree to start survey of new plant site", 17 May 2019, see https://www.world-nuclear-news.org/Articles/Russia-and-Uzbekistan-agree-to-start-survey-of-new, accessed 1 May 2021.

885 - *NIW*, "Uzbekistan – Site Selected for First Nuclear Plant", *Nuclear Intelligence Weekly*, 1 July 2022.

886 - *NEI Magazine*, "Uzbekistan's energy plans", 29 July 2020, see https://www.neimagazine.com/features/featureuzbekistans-energy-plans-8051183/, accessed 1 May 2021.

887 - *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.

888 - *NIW*, "Briefs – Vietnam", *Nuclear Intelligence Weekly*, 28 November 2016.

889 - 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.

and Japanese projects had been "suspended" in 2016, not "canceled", implying that authorities could revive the project.[890]

In the meantime, renewable capacity deployment in Vietnam represents 40 percent of the expected increase over the period 2021–2026 in all ASEAN countries.[891] In 2020 alone, a total of 9.3 GW of rooftop solar was installed. The country already has over 100,000 rooftop solar installations.

A September 2021 draft of the Power Development Plan (PDP8) proposes to raise coal-fired powers capacity by 3 GW by 2030. This would see a further 10 GW of coal capacity installed by 2035. The plan sacrifices 8 GW of renewables in a pivot back to coal from an earlier draft of the Plan. However, non-hydro renewables would still reach an installed capacity of 32.8 GW by 2030.[892]

890 - Myriam Boulianne, "Southeast Asia tempted by nuclear power", *Le Monde.fr*, 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.

891 - IEA, "Renewables 2021", revised version, December 2021.

892 - Viktor Tachev, "The Proposed Vietnam PDP8 Update and the Risks From the Coal Pivot", *Energy Tracker Asia*, 22 June 2022, see https://energytracker.asia/the-proposed-vietnam-pdp8-update-and-the-risks-from-the-coal-pivot/, accessed 24 August 2022.

SMALL MODULAR REACTORS

Small modular (nuclear) reactors or SMRs continue to hog the headlines in many countries, even though all the evidence so far shows that they will likely face major economic challenges and not be competitive on the electricity market. Despite this evidence, nuclear advocates argue that these untested reactor designs are the solution to the nuclear industry's woes. Other labels describing such untested designs are Generation IV reactors or Advanced Reactors or, most recently, microreactors. Hereafter, we update our earlier analyses of SMR programs (WNISR2015, WNISR2017, WNISR2019, WNISR2020, and WNISR2021) in selected countries (in alphabetical order).

ARGENTINA

CAREM-25 (the Central ARgentina de Elementos Modulares) is a pressurized water reactor with an output of around 30 MW(e) that is being constructed by Argentina's National Atomic Energy Commission (Comisión Nacional de Energía Atómica or CNEA). Its first pour of concrete dates back to February 2014,[893] and this was after nearly 30 years of developing the design.[894] At that time, CNEA announced that the reactor was "scheduled to begin cold testing in 2016 and receive its first fuel load in the second half of 2017".[895] In 2019, it was rescheduled to begin operating in 2022.[896] The reactor is nowhere close to that schedule and the latest estimated date for its startup is 2027.[897] It is also projected that the reactor's commissioning tests will take place in 2026.

"Even at the lower cost estimate of US$520 million, the per unit cost of the project is around US$17,000/kW, roughly twice the cost estimate of the most expensive Generation-III reactors"

However, late in 2019, Techint Engineering & Construction, the main contractor, halted work, citing late payment from the Government, unanticipated design changes and late delivery of technical documentation. In April 2020, reports suggested that the dispute had been resolved and that work should begin again in May 2020; there is no information available about the impact on the project timeline.[898] In an April 2021 interview, Hadid M. Subki, nuclear engineer

893 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2021.

894 - Silvia Lucila Molina, Natalia Sofía Tucci Branco and María Noelia Dusau, "CAREM Reactor: An Innovative and Achievable Option for Enhancing Nuclear Energy Supply", 4 November 2018, see https://emirates.meeting-app.events/inla2018/congress-papers/, accessed 29 June 2019.

895 - *WNN*, "Construction of CAREM Underway" February 2014, op. cit.

896 - *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.

897 - Daniel E. Arias, "'El CAREM, un salto cualitativo para el sector nuclear argentino'. Por eso, AgendAR propone una UTE" [""CAREM, a qualitative leap for the Argentine nuclear sector". For this reason, AgendAR proposes a joint venture."], AgendAR (in Spanish), 5 June 2022, see https://agendarweb.com.ar/2022/06/05/el-carem-un-salto-cualitativo-para-el-sector-nuclear-argentino-por-eso-agendar-propone-una-ute/, accessed 18 June 2022.

898 - Dan Yurman, "Argentina Plans To Revive CAREM-25 SMR", *NucNet*, as published on *Energy Central*, 26 April 2020, see https://energycentral.com/c/ec/argentina-plans-revive-carem-25-smr, accessed 26 June 2021.

with the IAEA's Department of Nuclear Energy, stated that "CAREM-25 is approaching prototype operation"; however, there is no evidence to support this assertion.[899]

In July 2021 CNEA announced that NA-SA had been contracted, and that "this new contract establishes a duration of 36 months to complete the reactor building".[900] After the civil work is terminated, it could take two additional years or more before the reactor is operational.[901]

CNEA estimated in 2005 that CAREM would cost about US$105 million.[902] That had gone up to US$446 million when construction started in 2014.[903] There is no definitive current cost estimate; however, in a media interview from June 2022, the manager of the CAREM project pointed out that fabricating the pressure vessel "has already taken [US]$52 million from the project, which is roughly 10% of the total budget",[904] suggesting that the overall budget is at least US$520 million. The GI Hub, a not-for-profit organization created by the G20, estimated that the project will cost US$750 million.[905] Even at the lower cost estimate of US$520 million, the per unit cost of the project is around US$17,000/kW, roughly twice the cost estimate of the most expensive Generation-III reactors.

CANADA

Canada federal government and several of the provincial governments have continued to promote SMRs. Promotion started in 2018 when the federal government funded the Canadian Nuclear Association, "a non-profit organization established in 1960 to represent the nuclear industry in Canada and promote the development and growth of nuclear technologies for peaceful purposes" to produce a "roadmap which will identify the opportunities for on and off-grid applications of Small Modular Reactors (SMRs) in Canada".[906] The federal government has awarded CAD20 million (around US$16 million) to Terrestrial Energy,[907] and CAD50.5 million

899 - *NEI Magazine*, "Prospects for small reactors", Interview with Hadid M. Subki, Nuclear Engineer, SMR Technology Development, Department of Nuclear Energy, IAEA, 28 April 2021, see https://www.neimagazine.com/features/featureprospects-for-small-reactors-8707333/, accessed 7 May 2021.

900 - CNEA, "CNEA y la empresa NA-SA firman un contrato para completar la construcción del CAREM" ["CNEA and the company NA-SA sign a contract to complete the construction of CAREM"], Press Release (in Spanish), 5 July 2021, see https://www.argentina.gob.ar/noticias/cnea-y-la-empresa-na-sa-firman-un-contrato-para-completar-la-construccion-del-carem, accessed 8 July 2021.

901 - Ignacio Ortiz, "La transición energética revaloriza el proyecto Carem", *Más Energía* (in Spanish), 4 December 2021, see https://mase.lmneuquen.com/transicion-energetica/la-transicion-energetica-revaloriza-el-proyecto-carem-n866539, accessed 11 April 2022.

902 - 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.

903 - *WNN*, "Construction of CAREM Underway", February 2022, op. cit.

904 - Matías Alonso and *Agencia TSS*, "Sol Pedre: 'El CAREM es un salto cualitativo para el sector nuclear argentino'", Universidad Nacional de San Martin (in Spanish), 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.

905 - Global Infrastructure Hub, "Quality Infrastructure Database/Case Studies/CAREM 25 (prototype)", 25 January 2021, see https://www.gihub.org/quality-infrastructure-database/case-studies/carem-25-prototype/, accessed 4 July 2022.

906 - NRCAN, "Canadian Small Modular Reactor (SMR) Roadmap", Natural Resources Canada, Natural Resources Canada, Updated 11 August 2018, see https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/canadian-small-modular-reactor-smr-roadmap/21084; and CNA, "About—Members", Canadian Nuclear Association, as of 2020, see https://cna.ca/about-cna/members/, accessed 13 October 2020.

907 - Terrestrial Energy, "Terrestrial Energy Receives Canadian Government Funding for IMSR Generation IV Nuclear Plant", Press Release, 15 October 2020, see http://www.terrestrialenergy.com/2020/10/terrestrial-energy-receives-canadian-government-funding-for-imsr-generation-iv-nuclear-plant/, accessed 21 June 2021.

(around US$40 million) to Moltex,[908] both companies that are pursuing molten salt reactor designs. And in March 2022, the federal government awarded CAD27 million (around US$21 million) to Westinghouse to support the eVinci microreactor design.[909] The province of New Brunswick awarded CAD20 million (around US$16 million) to ARC-100, a sodium cooled fast reactor design.[910] Earlier in 2018, the province had awarded CAD5 million (US$3.9 million) each to ARC-100 and Moltex.[911]

In July 2022, the federal government has, through its Atlantic Canada Opportunities Agency, awarded CAD786,250 to the Organization of Canadian Nuclear Industries to "identify and assist existing Atlantic Canadian companies" in transitioning to supplying components and services to the SMR industry.[912] Most of these companies, if not all of them, are likely to be in New Brunswick because it is the only province with nuclear reactors in Atlantic Canada.

There is no experience with a microreactor like eVinci. The other two reactor designs—namely molten salt reactors and sodium cooled fast reactor—have well known problems. Molten salt reactors confront major technical challenges related to materials and the past operating record has been erratic.[913] Despite countries around the world spending tens of billions of dollars, sodium cooled fast reactors have not been commercially viable, and the use of sodium makes them prone to leaks and shutdowns.[914]

New Brunswick's provincial electricity utility, NB Power, is working with Moltex and ARC-100 to "advance their technologies for use in New Brunswick".[915] In 2018, the provincial government had declared that a second reactor should be built at the Point Lepreau site.[916]

908 - Jacques Poitras, "Feds to put millions into small nuclear reactor development in N.B.", *CBC News*, 18 March 2021, see https://www.cbc.ca/news/canada/new-brunswick/feds-millions-small-nuclear-reactors-1.5955274, accessed 18 March 2021.

909 - Kevin Clark, "Canada invests $27 million in Westinghouse eVinci micro reactor", *Power Engineering*, 17 March 2022, see https://www.power-eng.com/nuclear/canada-invests-27-million-in-westinghouse-evinci-micro-reactor/, accessed 8 July 2022.

910 - Jacques Poitras, "Nuclear energy company gets $20M boost from province, Higgs says", *CBC*, 15 January 2021, see https://www.cbc.ca/news/canada/new-brunswick/small-modular-nuclear-reactors-new-brunswick-1.5908995, accessed 21 June 2021.

911 - *WNN*, "Moltex partners in New Brunswick SMR project", 16 July 2018, see https://www.world-nuclear-news.org/Articles/Moltex-partners-in-New-Brunswick-SMR-project, accessed 11 July 2022.

912 - OCNI, "Organization of Canadian Nuclear Industries (OCNI) receives funding to launch the Ready4SMR Program", Press Release, as published on *EIN News*, 29 July 2022, see https://www.einnews.com/pr_news/583493900/organization-of-canadian-nuclear-industries-ocni-receives-funding-to-launch-the-ready4smr-program, accessed 1 August 2022.

913 - M. V. Ramana, "Molten salt reactors were trouble in the 1960s—and they remain trouble today", *Bulletin of the Atomic Scientists*, 20 June 2022, see https://thebulletin.org/2022/06/molten-salt-reactors-were-trouble-in-the-1960s-and-they-remain-trouble-today/, accessed 21 June 2022; and M. V. Ramana, "Nuclear power: Why molten salt reactors are problematic and Canada investing in them is a waste", *The Conversation*, 14 September 2021, see http://theconversation.com/nuclear-power-why-molten-salt-reactors-are-problematic-and-canada-investing-in-them-is-a-waste-167019, accessed 20 December 2021.

914 - IPFM, "History and status of fast breeder reactor programs worldwide", International Panel on Fissile Materials, 17 February 2010, see https://fissilematerials.org/blog/2010/02/history_and_status_of_fas.html, accessed 3 October 2021; also S. Rajendran Pillai and M. V. Ramana, "Breeder reactors: A possible connection between metal corrosion and sodium leaks", *Bulletin of the Atomic Scientists*, 1 May 2014.

915 - Alex Woodworth, "An Update on Advanced Small Modular Reactor (SMR) in New Brunswick", NB Power, *INSiGHT Magazine*, as published by Fredericton Chamber of Commerce, 25 April 2021, see https://www.frederictonchamber.ca/insight/2021/04/25/an-update-on-advanced-small-modular-reactor-smr-in-new-brunswick/, accessed 21 June 2021.

916 - Kevin Bissett, "New Brunswick should have second nuclear reactor: energy minister", *The Canadian Press*, as published on *The Western Star*, 9 July 2018.

NB Power is supposed to shut down its last coal plant by 2030,[917] but former NB Power officials have admitted that these reactors might not be ready by that date.[918]

Two other electricity utilities, Ontario Power Generation (OPG, in Ontario) and SaskPower (in Saskatchewan), have selected GE Hitachi's BWRX-300 for potential deployment.[919] OPG plans to construct this at the Darlington site, for which OPG holds a site preparation license; in 2021 it applied to renew this license.[920] OPG has announced that the reactor could be completed as early as 2028.[921] SaskPower, on the other hand, has deferred the decision on whether or not to build an SMR to 2029.[922]

There is good reason to be skeptical of these dates. The BWRX-300 is based on GE-Hitachi's Economic Simplified Boiling Water Reactor (ESBWR) design, which was submitted for licensing to the U.S. Nuclear Regulatory Commission in 2005.[923] That design was changed nine times; the NRC finally approved revision 10 that was submitted in 2014.[924] The BWRX-300 has not been licensed for construction anywhere, and has not yet been submitted for formal licensing either in Canada or the United States.[925]

The Canadian Nuclear Safety Commission (CNSC) has been offering the "pre-licensing vendor design review", an optional service for SMR vendors, as a way to signal its readiness to license SMRs. However, CNSC does make it clear that such a review is "not an application for a licence to prepare a site or to construct or operate a nuclear power facility" and that the "review does not certify a reactor design or involve the issuance of a licence" and that the "conclusions of any design review do not bind or otherwise influence decisions made by the Commission".[926] Since WNISR2021, no reactor design has been submitted for such a review.

There is one SMR proposal that is being reviewed by CNSC for possible construction at the Chalk River Laboratories site in the province of Ontario: the 15 MW (thermal) Micro Modular

917 - Jacques Poitras, "No extension past 2030 for Belledune coal-fired power plant, Ottawa says", *CBC News*, 25 November 2021, see https://www.cbc.ca/news/canada/new-brunswick/belledune-coal-plant-ottawa-1.6262023, accessed 4 July 2022.

918 - Jacques Poitras, "Small modular reactors might not be ready by 2030, former N.B. Power CEO warns", *CBC News*, 19 January 2022, see https://www.cbc.ca/news/canada/new-brunswick/small-nuclear-reactor-delay-gaetan-thomas-1.6320770, accessed 4 July 2022.

919 - *WNN*, "OPG chooses BWRX-300 SMR for Darlington new build", 2 December 2021, see https://www.world-nuclear-news.org/Articles/OPG-chooses-BWRX-300-SMR-for-Darlington-new-build; and Drew Postey, "SaskPower selects SMR that could be used to generate nuclear power in 2030s", *CTV News*, 27 June 2022, see https://regina.ctvnews.ca/saskpower-selects-smr-that-could-be-used-to-generate-nuclear-power-in-2030s-1.5965261; both accessed 4 July 2022.

920 - David Dalton, "OPG Applies For Renewal Of Darlington Nuclear Site Licence", *NucNet*, 22 March 2021, see https://www.nucnet.org/news/opg-applies-for-renewal-of-darlington-nuclear-site-licence-3-1-2021, accessed 21 June 2021.

921 - OPG, "OPG advances clean energy generation project", Press Release, 2 December 2021, see https://www.opg.com/media_releases/opg-advances-clean-energy-generation-project/, accessed 19 September 2022.

922 - Drew Postey, "SaskPower Selects SMR That Could Be Used to Generate Nuclear Power in 2030s", *CTV News*, June 2022, op. cit.

923 - David B. Matthews, "Acceptance of the General Electric Company application for final design approval and standard design certification for the Economic Simplified Boiling Water Reactor (ESBWR) design", Division of New Reactor Licensing, Office of Nuclear Reactor Regulation, Nuclear Regulatory Commission, December 2005, see https://www.nrc.gov/docs/ML0532/ML053200311.pdf, accessed 6 July 2022.

924 - U.S.NRC, "NRC: Package ML14104A929 - GE-Hitachi ESBWR Design Control Document Tier, Revision 10.", U.S. Nuclear Regulatory Commission, 14 April 2014, see https://www.nrc.gov/docs/ML1410/ML14104A929.html, accessed 6 July 2022.

925 - It is undergoing pre-application review at the NRC and a pre-licensing vendor design review at the CNSC. See U.S.NRC, "New Reactors: GEH BWRX-300", U.S. Nuclear Regulatory Commission, Updated 18 May 2022, see https://www.nrc.gov/reactors/new-reactors/smr/bwrx-300.html; and *WNN*, "Canadian pre-licensing review starts for BWRX-300", 22 May 2019, see https://world-nuclear-news.org/Articles/Canadian-pre-licensing-review-starts-for-BWRX-300, both accessed 6 July 2022.

926 - CNSC, "Pre-Licensing Vendor Design Review", Canadian Nuclear Safety Commission, Updated 25 May 2021, see https://cnsc.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm, accessed 20 June 2021.

Reactor Project being developed by a company called Global First Power along with Ultra Safe Nuclear Corporation and Ontario Power Generation. A CNSC license is required in order for the project to proceed; however, before this decision can be made, the project has to undergo an environmental assessment.[927]

Chalk River is located on "Algonquin Anishinabeg Nation territory and the lands of Kebaowek First Nation – a First Nation that has never been consulted about the use of its unceded territory and that has been severely affected by past nuclear accidents at the site".[928] The Kebaowek First Nation has been "vocal in its objection to the continuation of the nuclear industry on its lands without its free prior and informed consent, as is its right under the United Nations Declaration on the Rights of Indigenous Peoples".[929]

According to its proponents, the Micro Modular Reactor Project is intended to be "a commercial demonstration reactor" and "a model… to provide safe and sustainable low-carbon power and heat to industries, such as mining, and remote communities".[930] The net electricity demand from remote mines and communities in Canada are insufficient to develop the facilities needed to manufacture SMRs, and the costs of the electricity any reactors small enough to power a remote mine or community would be prohibitively high.[931] There is no official cost figure for the Micro Modular Reactor Project but Global First Power said during an "SMR Telephone Town Hall" in May 2020 that the project would cost in the range of CAD100–200 million.[932] Since the MMR can generate only 5 MW(e), that translates to very high figures of CAD20,000—40,000 (roughly US$15,000–30,000) per kilowatt of electric capacity. In comparison, OPG has estimated that a 300 MW SMR will cost CAD3 billion, or around CAD10,000 (roughly US$7,500/kW).[933]

CHINA

As reported in China Focus, the first SMR was connected to the grid on 20 December 2021. The progress of the HTR-PM project has been described in earlier WNISRs. Delays and cost escalation in this project offer an excellent illustration of why SMRs are likely to be no different from reactors with higher power ratings. The delays go back to even before construction started. The HTR-PM has a long history of development, and can be traced back to the late

927 - CNSC, "Global First Power Micro Modular Reactor Project", Canadian Nuclear Safety Commission, 18 May 2021, see https://www.nuclearsafety.gc.ca/eng/reactors/research-reactors/nuclear-facilities/chalk-river/global-first-micro-modular-reactor-project.cfm, accessed 7 July 2022.

928 - Lance Haymond, Tasha Carruthers and Kerrie Blaise, "Decolonizing Energy and the Nuclear Narrative of Small Modular Reactors", *Policy Options*, 7 February 2022, see https://policyoptions.irpp.org/magazines/february-2022/decolonizing-energy-and-the-nuclear-narrative-of-small-modular-reactors/, accessed 7 July 2022.

929 - Ibidem.

930 - OPG, "Global First Power, Ultra Safe Nuclear Corp. and OPG form joint venture on MMR at Chalk River", Ontario Power Generation, Press Release, 9 June 2020, see https://www.opg.com/media_releases/gfp-usnc-and-opg-form-joint-venture-on-mmr-at-chalk-river/, accessed 7 July 2022.

931 - Sarah Froese, Nadja C. Kunz and M.V. Ramana, "Too Small to be Viable? The Potential Market for Small Modular Reactors in Mining and Remote Communities in Canada", *Energy Policy*, Vol. 144, September 2020, see https://www.sciencedirect.com/science/article/abs/pii/S030142152030327X, accessed 3 July 2020.

932 - Concerned Citizens of Renfrew County and Area, "Decision on the scope of an environmental assessment of the proposed Micro Modular Reactor Project at the Canadian Nuclear Laboratories Ltd., in Chalk River", Canadian Nuclear Safety Commission, June 2020.

933 - OPG, "Natural Gas Phase-Out Study—Data Tables", 7 October 2021, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/gas-phase-out/natural-gas-phase-out-study-ieso-data-tables.ashx, accessed 17 September 2022.

1980s when a joint venture of Siemens and ABB developed the 80 MW HTR-MODUL.[934] In 2004, after the smaller HTR-10 started operating, the CEO of Chinergy, a 50-50 joint venture between Tsinghua University's Institute for Nuclear and New Energy Technology and the state-owned China Nuclear Engineering Group, forecast that construction of the first plant would start in "Spring 2007" and the plant would start operating "by the end of the decade".[935] The project was high-profile and was listed in the National Guideline on Medium- and Long-Term Program for Science and Technology Development" in 2006.[936] The following year, a study claimed that "the maximum costs of an HTR-PM plant will not exceed the costs of an equivalent PWR by more than 20%".[937]

None of that happened. Construction started only in 2012, and by then the time estimate had increased to "50 months".[938] In reality, the first unit took almost 109 months to go from first pour of concrete to grid connection, more than twice as long as anticipated, while the startup of the second unit had not been reported yet as of mid-2022.

The prediction about the cost difference with PWRs too has proven to be incorrect, with the World Nuclear Association (WNA) reporting a construction cost of US$6,000 per kW for these units, as compared to indicative figures in the range of US$2,600–US$3,500/kW for Hualong-One reactors.[939]

There appear to be no plans to construct more reactors of the same design.

However, in November 2020, China National Nuclear Corporation (CNNC) released "four tender documents soliciting technology partners for conducting marine environmental, seismic, geology, and safety assessments at a completely new nuclear site: Xin'an, a town within Haiyang City in Shandong province" and according to the tender documents "CNNC plans to first construct two 600 MW HTGRs at the newly unveiled site".[940] The larger power level suggests that CNNC is scaling up the reactor to gain from economies of scale; at 600 MW, these new reactor designs would no longer fit the IAEA definition of a small reactor as being one that generates less than 300 MW.

Construction of the second SMR design—the ACP100—started in July 2021.[941] The project is named Linglong One although it is at the Changjiang site in Hainan province, which is already

934 - Steve Thomas, Paul Dorfman et al., "Prospects for Small Modular Reactors in the UK and Worldwide", nuclear consulting group, Nuclear Free Local Authorities, July 2019, see https://nuclearconsult.com/wp/wp-content/uploads/2019/07/Prospects-for-SMRs-report-2.pdf.

935 - Spencer Reiss, "Let a Thousand Reactors Bloom", *Wired*, 1 September 2004, see https://www.wired.com/2004/09/china-5/, accessed 16 July 2022. See also Zuoyi Zhang 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.

936 - INET, "HTR-PM", Institute of Nuclear and New Energy Technology, Tsinghua University, 2010, see https://www.inet.tsinghua.edu.cn/ineten/kpj/HTR_PM.htm, accessed 16 July 2022.

937 - Zuoyi Zhang and Yuliang Sun, "Economic potential of modular reactor nuclear power plants based on the Chinese HTR-PM project", Institute of Nuclear and New Energy Technology, Tsinghua University, *Nuclear Engineering and Design*, December 2007.

938 - 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 9 January 2013.

939 - WNA, "Nuclear Power in China", World Nuclear Association, February 2022, see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx, accessed 28 February 2022.

940 - C.F. Yu, "CNNC Rolls Out Additional HTGR Plans", *Nuclear Intelligence Weekly*, 13 November 2020.

941 - CNNC, "World's first commercial Linglong One onshore small reactor starts construction", Press Release, 14 July 2021, see https://en.cnnc.com.cn/2021-07/14/c_642603.htm, accessed 31 August 2021; WNA, "Changjiang SMR-1, China", Undated, see https://www.world-nuclear.org/reactor/default.aspx/CHANGJIANG%20SMR, accessed 30 November 2021.

home to two operating CNP600 PWRs, and two Hualong One units under construction. According to CNNC, construction is proceeding rapidly and is 70 days ahead of schedule.[942]

A look at the longer history reveals that the ACP100 design is delayed. The first public proposal for an ACP100 came from the Chinese National Nuclear Corporation (CNNC) in 2010.[943] By the end of 2010, Gansu Province listed the reactor into its "12th Five Year Plan". In November 2011, CNNC New Energy Corporation, a joint venture between CNNC and China Guodian Corporation, and the Zhangzhou municipal government signed an agreement to construct two ACP100 SMRs at a cost of around RMB5 billion (US$$_{2011}$787 million).[944] At the same time, other reports mentioned construction of the first ACP100 to be started in 2013 in Putian, Fujian Province.[945] This was repeated in a CNNC presentation in 2014.[946]

Start of construction was initially slated for 2015, according to a 2012 official presentation.[947] The same date was reported by the IAEA in 2013.[948] By late 2014, construction had been pushed back to 2016.[949] In 2016, start of construction was planned for 2017.[950] Thus, by the time construction started in 2021, this SMR was at least six years late. At the time of first pour of concrete, a CNNC official predicted that construction of the reactor "will be completed in 58 months" by early 2026.[951]

The reactor will also not be economical. Even prior to the start of construction, CNNC admitted that the construction cost per kilowatt of the proposed ACP100 demonstration project "is 2 times higher than that of a large NPP [nuclear power plant]".[952] Small pressurized water reactors like the ACP100 also have higher fuel chain costs.[953]

There are a number of other SMR designs at various stages of development but none of them are reportedly slated for construction anytime soon.[954] In 2020, CNNC submitted a project proposal to construct a district heating reactor, a pool type reactor with a thermal power of

942 - *WNN*, "Rapid construction of Chinese SMR containment shell continues", 7 July 2022, see https://www.world-nuclear-news.org/Articles/Rapid-construction-of-Chinese-SMR-containment-shel, accessed 17 July 2022.

943 - Dynabond, "China has begun to develop and apply those small reactors", 4 August 2011.

944 - *WNN*, "Small reactors planned for Zhangzhou", 17 November 2011, see http://www.world-nuclear-news.org/NN-Small_reactors_planned_for_Zhangzhou-1711115.html, accessed 5 January 2012.

945 - Brian Wang, "China will start to build the ACP100 Pressure Water Nuclear Reactor in 2013", *NextBigFuture*, 16 July 2012, see https://www.nextbigfuture.com/2012/07/china-will-start-to-buildthe-acp100.html, accessed 16 July 2022.

946 - CNNC, "Progress of SMR ACP100 Series", 25 September 2014, see https://www.nuclearinst.com/write/MediaUploads/CNNC.pdf, accessed 16 July 2022.

947 - Li Jinying, "Market Analysis of Chinese SNRs (small nuclear reactors)", 2nd Annual Small Modular Reactor Conference, 24 April 2012.

948 - Hadid Subki, "Global Development Trends, Prospects and Issues for SMRs Deployment", SMR Technology Development, Nuclear Power Technology Development Section, Division of Nuclear Power, Department of Nuclear Energy, International Atomic Energy Agency, presented at the 23rd Meeting of the Technical Working Group on Gas Cooled Reactors (TWG-GCR), IAEA, 5 March 2013.

949 - Hadid Subki, "Advances in Reactor Technology for Water Cooled Reactors & Small Modular Reactors", IAEA, 24 September 2014.

950 - Phil Chaffee, "CNNC Looks to UK for SMR Effort", *Nuclear Intelligence Weekly*, 3 March 2017.

951 - *TASS*, "Construction of the world's first small modular reactor to be completed on Hainan in 2026", 15 July 2021, see https://tass.com/economy/1314135, accessed 20 July 2022.

952 - Danrong Song, "Opportunities and Challenges in SMR and Its Practice in ACP100", China National Nuclear Corporation, 2 July 2019, as presented at "INPRO Dialogue Forum on Opportunities and Challenges in SMR", 2–5 July 2019, Ulsan Republic of Korea, see https://nucleus.iaea.org/sites/INPRO/df17/IV.1.-DanrongSong-ACP100.pdf, accessed 4 July 2020.

953 - Assil Halimi and Koroush Shirvan, "Impact of core power density on economics of a small integral PWR", *Nuclear Engineering and Design*, 15 December 2021.

954 - C. F. Yu, "Chinese SMR Program Faces Slowdown and Secrecy", *Nuclear Intelligence Weekly*, 24 July 2020.

400 MW, to the National Energy Administration.[955] But so far this project does not appear to have been approved for construction.

FRANCE

France is the latest entrant to the list of countries that advertise themselves as SMR developers. Amidst all the tremendous challenges faced by the country's nuclear energy sector—or perhaps because of these challenges—in February 2022, as part of his election campaign, President Emmanuel Macron announced that "€1 billion (US$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".[956]

The Nuward project was announced in September 2019 by the French Alternative Energies and Atomic Energy Commission (CEA), EDF, Naval Group and TechnicAtome.[957] But it was clearly not a priority for EDF. In 2020, *Nuclear Intelligence Weekly* reported that EDF "remains almost exclusively focused on developing a more economic version of the EPR in the EPR2" and cited a source saying that there were "as many as 1,000 engineers involved" in that design in comparison to "10-15 engineers estimated to be working on the embryonic Nuward design".[958]

Despite the nascent stage at which the Nuward design was, in 2021, when EDF "submitted its case for building a fleet of six EPR2 newbuilds", the EDF Chairman and CEO Jean-Bernard Levy told shareholders that the Nuward SMR design "will be ready for deployment by 2030. And in order to give the product all its chances on the product markets, which are outside of France, we will suggest that in the next energy program we plan to build an SMR in France".[959] EDF has also been advancing Nuward as a "case study for a European early joint regulatory review" and this will involve cooperation between the French, Czech and Finnish nuclear safety authorities.[960]

This is not the first time France has been advancing an SMR design. In January 2011, EDF along with CEA, naval shipbuilding company DCNS, and the now-defunct company AREVA, announced that they were developing "an underwater small modular reactor" called "Flexblue".[961]

955 - Zengguang Lei, "Status of SMR R&D in China", China National Nuclear Corporation, 20 January 2021, see https://energiforsk.se/media/29029/leezenggung_cnnc.pdf, accessed 20 July 2022.

956 - *WNN*, "Macron sets out plan for French nuclear renaissance", 11 February 2022, see https://www.world-nuclear-news.org/Articles/Macron-announces-French-nuclear-renaissance, accessed 19 February 2022.

957 - *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.

958 - Phil Chaffee, "Atmea1 Abandoned as French-Japanese Cooperation Withers", *Nuclear Intelligence Weekly*, 17 April 2020.

959 - *NIW*, "EDF Submits Case for Six New EPR 2s", *Nuclear Intelligence Weekly*, 7 May 2021.

960 - EDF, "EDF announces that its Small Modular Reactor NUWARD™ 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/en/the-edf-group/dedicated-sections/journalists/all-press-releases/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, accessed 2 June 2022; and ASN, "Development of small modular reactors: in collaboration with the safety regulators of Finland and the Czech Republic, ASN is initiating an unprecedented joint preliminary examination of the NUWARD™ reactor project", Autorité de Sûreté Nucléaire, French Nuclear Safety Authority, Information Notice, 6 July 2022, see https://www.french-nuclear-safety.fr/asn-informs/news-releases/development-of-small-modular-reactors, accessed 7 July 2022.

961 - *NIW*, "France", *Nuclear Intelligence Weekly*, 24 January 2011.

During the previous decade, AREVA was also developing two other SMR designs. One was a High Temperature Gas Cooled Reactor called Antares (AREVA New Technology Advanced Reactor for Energy Supply) that, in 2009, it anticipated would be ready for deployment by 2021.[962] The second was a pressurized water reactor design called NP-300 based on submarine power plant designs.[963] All those designs seem to have been abandoned.

INDIA

India's Department of Atomic Energy (DAE) has been developing the Advanced Heavy Water Reactor (AHWR) design since the 1990s with plans to have one operating by 2011.[964] It has since been delayed continuously. In 2021, the Indian government announced that it had already "accorded in-principle approval" all the way back in 2016 for building the AHWR at the Tarapur site (which already has reactors and a reprocessing plant).[965] But in the intervening five years, there does not seem to be any actual plans for construction. Earlier in 2022, the government announced that a "Pre-Licensing Design Safety appraisal of the reactor has been completed by the Atomic Energy Regulatory Board" and that construction "can begin after associated statutory clearances, regulatory clearances and financial sanction for the project are obtained".[966] These announcements suggest that construction of the reactor might still take a while.

RUSSIA

Russia operates two SMRs, both based on the KLT-40S "floating" design, on a barge called the Akademik Lomonosov, in the eastern part of the country. Both reactors were connected to the grid in December 2019 and entered commercial operation in May 2020 after lengthy delays and cost overruns (see earlier WNISR editions). The 2021 load factors for the two reactors were just 44.7 and 18 percent according to the IAEA's PRIS database. These were slightly better than the 2020 load factors, but not significantly so. It is unclear why their performance is so mediocre.

Despite this poor experience with construction and operation, Russia's state-owned Rosatom has announced plans to build four new floating nuclear power plants, specifically to power mining operations in northern Siberia, at an estimated cost of €1.7 billion (US$1.7 billion); three of these are projected to be connected to the grid in 2026–2027, while one is to be kept in reserve and rotated when any of the three deployed plants require refuelling or maintenance.[967]

962 - Daniel T. Ingersoll, "Deliberately small reactors and the second nuclear era", *Progress in Nuclear Energy*, 2009.

963 - WNA, "Small Nuclear Power Reactors", World Nuclear Association, February 2010.

964 - V. K Chaturvedi, "CMD's page", Nu-Power, 2000.

965 - Rajya Sabha, "Unstarred question No. 3368—Uranium and Thorium reserves in the country", Department of Atomic Energy, answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions, Prime Minister's Office, Government of India, 25 March 2021, see https://dae.gov.in/writereaddata/rs%20usq%203368.pdf, accessed 23 June 2021.

966 - Lok Sabha, "Unstarred Question No. 226—Nuclear Power Plants", Department of Atomic Energy, answered by Jitendra Singh, Ministry of State for Personnel, Public Grievances & Pensions, Prime Minister's Office, Government of India, 2 February 2022, see https://dae.gov.in/writereaddata/lsusq226.pdf, accessed 20 February 2022.

967 - Steven Gislam, "Russia's Rosatom to build four new floating nuclear plants in Siberia", *Industry Europe*, 11 August 2021, see https://industryeurope.com/api/content/b47aa188-fa91-11eb-a44c-1244d5f7c7c6/;
and Charles Digges, "Russia advances on plans for new floating nuclear plants", Bellona, 17 September 2021, see https://bellona.org/news/nuclear-issues/2021-09-russia-advances-on-plans-for-new-floating-nuclear-plants, both accessed 24 July 2022.

The reactors powering these plants would not be of the KLT-40S design but 55 MW RITM-200 reactors.

Russia has been promoting the RITM design for over a decade, for use in icebreaker ships and floating and land-based nuclear plants.[968] Construction of the RITM for icebreaker ships started in 2012.[969] The IAEA's periodic update on the status of different SMR designs reported in 2018 that conceptual design of the land-based variant had started that year, and first concrete pour was to be carried out in 2022, with a nuclear plant commissioned in 2025.[970] By 2020, the date for commissioning had been pushed back to 2027,[971] a date also projected by the Marketing Director for Rosatom.[972] In November 2020, Rosatom announced plans to build a land-based RITM in the village of Ust-Kuyga, in Yakutia, in the far eastern part of Russia, and this was reiterated in a May 2022 announcement by Rosatom that lists this reactor among the ones to be built by 2035.[973] According to the World Nuclear Association, start of construction is planned for 2024.[974] The RITM-200 and the KLT-40S are part of a larger Russian strategy to develop the Arctic and eastern Siberia to obtain minerals and hydrocarbons.[975]

Russia is also developing fast neutron based SMR designs. The first of these, the lead cooled BREST-300, is under construction since June 2021 at the Siberian Chemical Combine (SCC) in Seversk.[976] Startup of the reactor is scheduled "before the end of 2026".[977] According to Yevgeny Adamov, former minister of atomic energy and a champion of lead-cooled fast reactors, BREST-300 should cost RUB100 billion (US$1.4 billion).[978]

The BREST design is significantly delayed. Under development since the start of this century, at that time, it was being considered for construction at the Beloyarsk site which hosts two operating fast breeder reactors.[979] The "Federal Program for Advanced Nuclear Technologies" adopted by Russia in January 2012 had called for building three commercial fast neutron

968 - IAEA, "Status of Small and Medium Sized Reactor Designs", International Atomic Energy Agency, September 2012.

969 - IAEA, "Advances in Small Modular Reactor Technology Developments", International Atomic Energy Agency, September 2014.

970 - IAEA, "Advances in Small Modular Reactor Technology Developments—2018 Edition", September 2018, Supplement to "Advanced Reactors Information System (ARIS)", International Atomic Energy Agency, see https://aris.iaea.org/Publications/SMR-Book_2018.pdf.

971 - IAEA, "Advances in Small Modular Reactor Technology Developments—2020 Edition", September 2020, Supplement to "IAEA Advanced Reactors Information System (ARIS)", International Atomic Energy Agency, see https://aris.iaea.org/Publications/SMR_Book_2020.pdf.

972 - Elena Pashina, "Rosatom RITM series SMRs", Rusatom Overseas, Rosatom, 23 June 2020, as presented at IFNEC, "SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits", International Framework for Nuclear Energy Cooperation, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 5 July 2020.

973 - *WNN*, "Rosatom plans first land-based SMR for Russian Far East", 11 November 2020, see https://www.world-nuclear-news.org/Articles/Rosatom-plans-first-land-based-SMR-for-Russian-Far, accessed 26 June 2021; and *NEI Magazine*, "Russia to build 16 new nuclear units by 2035", 1 June 2022, see https://www.neimagazine.com/news/newsrussia-to-build-16-new-nuclear-units-by-2035-9738009/, accessed 19 July 2022.

974 - WNA, "Nuclear Power in Russia", Updated April 2021, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 10 May 2021.

975 - Gary Peach, "Frontier Expansion via Floating NPPs", *Nuclear Intelligence Weekly*, 4 June 2021.

976 - 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 26 June 2021.

977 - *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.

978 - Gary Peach, "Construction Starts on Lead-Cooled Fast Reactor", *Nuclear Intelligence Weekly*, 11 June 2021.

979 - NEA, "Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles", Nuclear Energy Agency, OECD, 2002.

reactors by 2020, including the BREST-300 as well as the lead-bismuth cooled SVBR-100 and the sodium-cooled BN-1200.[980] That year, the federal budget allocated RUB25.7 billion (US$$_{2022}$480 million) for "the design and construction of the pilot demonstrative fast-neutron lead cooled reactor BREST".[981] By the following year, the Technical Lead of the IAEA's SMR Technology Development division projected that the BREST-300 and SVBR-100 would be deployed by 2018.[982] Clearly none of that happened. Further, the SVBR-100 may no longer be under development.[983]

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). In December 2021, *Nuclear Intelligence Weekly* revealed that there are some other designs being developed in the country, including a smaller capacity (70 MW thermal) light-water design called Advanced Reactor for Multipurpose Research Applications (ARA), the innovative SMR [i-SMR], and plans to develop a molten salt reactor and a sodium cooled fast reactor.[984] The molten salt reactor design was announced in June 2021 by KAERI and Samsung Heavy Industries.[985]

"There was not a single order for a SMART reactor within South Korea (it was never licensed elsewhere)."

The most significant of these seem to be the ARA and i-SMR designs. Korea Atomic Energy Research Institute (KAERI) projects that construction of the ARA will start in 2023 and start operating in 2027, but the reactor design involves the use of HALEU fuel with uranium enrichment of 19.75 percent, which has limited availability globally.[986] The i-SMR project is being developed in collaboration with Korea Hydro & Nuclear Power (KHNP) and officials are projecting that it would be approved for construction by 2028 and be available for exports by 2030.[987]

980 - Gary Peach, "Russia: Large Commercial Breeder Design Targeted for 2014", *Nuclear Intelligence Weekly*, 16 March 2012.

981 - Anatoli Diakov, "Status and prospects for Russia's fuel cycle", *Science & Global Security*, 2013.

982 - Hadid Subki, "Global Development Trends, Prospects and Issues for SMRs Deployment", SMR Technology Development, Nuclear Power Technology Development Section, Division of Nuclear Power, Department of Nuclear Energy, International Atomic Energy Agency, presented at the 23rd Meeting of the Technical Working Group on Gas Cooled Reactors (TWG-GCR), IAEA, 5 March 2013.

983 - WNA, "Generation IV Nuclear Reactors", Updated December 2020, World Nuclear Association, December 2020, see https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors.aspx, accessed 26 June 2021; also Anatoli Diakov and Pavel Podvig, "Construction of Russia's BN-1200 fast-neutron reactor delayed until 2030s", IPFM, 20 August 2019, see http://fissilematerials.org/blog/2019/08/the_construction_of_the_b.html, accessed 7 July 2020.

984 - Stephanie Cooke, "Kaeri's ARA SMR Push Raises Eyebrows", *Nuclear Intelligence Weekly*, 3 December 2021.

985 - 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.

986 - Stephanie Cooke, "Kaeri's ARA SMR Push Raises Eyebrows", *Nuclear Intelligence Weekly*, 3 December 2021.

987 - Yoon So-Yeon, "Small nuclear reactors and other tech may help reduce emissions", *Korea JoongAng Daily*, 28 October 2021, see https://koreajoongangdaily.joins.com/2021/10/28/business/tech/renewable-energy-SMR-bioenergy/20211028180827686.html; and Young A Suh, "Considerations of regulators and developers for SMR development: The case of US NRC", KINS, 19 May 2022, in Transactions of the Korean Nuclear Society Spring Meeting, Korea Institute of Nuclear Safety, see https://www.kns.org/files/pre_paper/47/22S-111-%EC%84%9C%EC%98%81%EC%95%84.pdf, both accessed 1 August 2022.

All of these plans seem implausible in light of the experience with KAERI's earlier SMART design. Although it received a Standard Design Approval from Korea's Nuclear Safety and Security Commission over a decade ago,[988] there was not a single order for a SMART reactor within South Korea (it was never licensed elsewhere). The main challenge has been adverse economics, with a "target overnight plant construction cost" of a first-of-a-kind plant being estimated at US$10,000/kW(e).[989] The high cost is likely the reason that in April 2021, KHNP announced 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".[990]

Since 2015, when KAERI signed a Memorandum of Understanding with the King Abdullah City for Atomic and Renewable Energy (KA-CARE), South Korea has been trying to export the SMART reactor to Saudi Arabia, and to other middle eastern countries.[991] The agreement was updated in January 2020 to include KHNP as a participant in "the construction of the first SMART unit".[992] However, in May 2022, when Saudi Arabia invited South Korea to put in a bid to construct reactors in Saudi Arabia, it was to build two APR1400 reactors.[993] There was no mention of SMART reactors.

UNITED KINGDOM

The United Kingdom's interest in SMRs follows a 2014 feasibility study carried out by the National Nuclear Laboratory and funded by seven nuclear organizations, including Rolls Royce.[994] Since then, Rolls Royce has developed the "UK SMR" design, which is said to be capable of generating 470 MW, i.e., not meeting the definition of an SMR.[995]

Other SMR vendors, such as NuScale in the United States,[996] have also increased the power outputs for their SMR designs, presumably to take advantage of economies of scale. In November 2021, Rolls Royce submitted its design to the Office of Nuclear Regulation (ONR),

988 - Kwon Dong-joon and Korea IT News, "Korean All-in-one SMR Won World's First Standard Design Approval", *Electronic Times Internet*, 5 July 2012, see http://english.etnews.com/20120705200008, accessed 1 May 2017.

989 - See page 56 in IAEA, "Advances in Small Modular Reactor Technology Developments—2020 Edition", op. cit.

990 - 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 23 June 2021.

991 - *WNN*, "Saudi Arabia teams up with Korea on SMART", 4 March 2015, see https://www.world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html, accessed 14 May 2020.

992 - *WNN*, "Korea, Saudi Arabia progress with SMART collaboration", 7 January 2020, see https://world-nuclear-news.org/Articles/Korea-Saudi-Arabia-progress-with-SMART-collaborati, accessed 14 May 2020.

993 - Zi-Hoon Lee and So-Hyeon Kim, "S.Korea to bid for Saudi Arabia's $10 bn nuclear plant order", *KED Global*, 31 May 2022, see https://www.kedglobal.com/energy/newsView/ked202205310016, accessed 3 June 2022.

994 - *WNN*, "National Nuclear Laboratory urges UK investment in SMRs", 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.

995 - *WNN*, "Rolls-Royce on track for 2030 delivery of UK SMR", 11 February 2021, see https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR, accessed 26 June 2021.

996 - Stephanie Cooke, "NuScale Moves to Larger-Scale Modules", *Nuclear Intelligence Weekly*, 12 February 2021; and M. V. Ramana, "Eyes wide shut: Problems with the Utah associated municipal power systems proposal to construct NuScale small modular nuclear reactors", Oregon Physicians for Social Responsibility, September 2020, see https://www.oregonpsr.org/small_modular_reactors_smrs, accessed 13 October 2020.

which accepted it for a Generic Design Assessment (GDA) review in March 2022; the chairman of Rolls Royce announced that the process "will likely complete in the middle of 2024".[997]

Also in November 2021, Rolls Royce announced that it had received £210 million (US$281 million) in government funding and £195 million (US$261 million) in private funds from "Rolls-Royce itself as well as from Exelon Nuclear Partners, a subsidiary of the largest U.S. nuclear operator, and BNF Resources UK, a vehicle of France's wealthy Perrodo family that owns the Perenco oil and gas firm".[998] The following month, it received £85 million (US$112 million) in funding from the Qatar Investment Authority (Qatar's sovereign fund).[999] All of these investors will get stakes in the company. These investments must be seen in light of Rolls Royce's earlier calls for around £2 billion (US$2.8 billion) of U.K. government funding to move forward with its plans.[1000]

For more on the U.K.'s SMR program, see United Kingdom Focus in this report.

UNITED STATES

Nuclear advocates in the United States continue to actively promote SMRs, making many untenable claims made about them. Alongside the growing publicity, there is also more funding going into SMRs for a whole range of activities. The budget watchdog organization, Taxpayers for Common Sense, has calculated that as of December 2021, the U.S. Department of Energy (DOE) has spent "more than [US]$1.2 billion on SMRs" and has announced further awards over the next decade that could amount to "at least [US]$5.5 billion more" than what has already been invested.[1001] This includes funding for companies developing SMR designs, and also funding to create the perception of demand, for example to a study to examine the suitability of Puerto Rico for deploying SMRs.[1002] Likewise, at the 2022 G7 Leaders' Summit, during the launch of the Partnership for Global Infrastructure and Investment, U.S. President Joe Biden announced a US$14 million grant for the development of SMRs in Romania.[1003] But

997 - *WNN*, "Rolls-Royce hopes for UK SMR online by 2029", 19 April 2022, see https://www.world-nuclear-news.org/Articles/Rolls-Royce-hopes-for-UK-SMR-online-by-2029, accessed 19 April 2022.

998 - Phil Chaffee, "Newbuild: Financing the SMRs of Rolls-Royce, GE and NuScale", *Nuclear Intelligence Weekly*, 12 November 2021.

999 - 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 1 August 2022.

1000 - Charlotte Ryan and Rachel Morison, "Rolls-Royce Renews Call for $2.8 Billion to Build U.K. Reactors", *Bloomberg*, 21 May 2021, see https://www.bloomberg.com/news/articles/2021-05-21/rolls-royce-renews-call-for-2-8-billion-to-build-u-k-reactors, accessed 24 May 2021.

1001 - Taxpayers for Common Sense, "Doubling Down: Taxpayers' Losing Bet on NuScale and Small Modular Reactors", December 2021, see https://www.taxpayer.net/energy-natural-resources/doubling-down-losing-bet-on-small-modular-reactors-nuclear/, accessed 12 January 2022.

1002 - Office of Nuclear Energy, "The Nuclear Alternative Project Abstract", U.S. Department of Energy, 23 November 2021, see https://www.energy.gov/ne/articles/nuclear-alternative-project-abstract, accessed 5 August 2022.
Even though the study has not been completed, the DOE website confidently asserts "Results of the study will support DOEs mission to commercialize these technologies in small island and/or remote locations".

1003 - Nuclearelectrica, "$14 million grant announced by President Biden for the development of small modular reactors (SMRs) in Romania", Press Release, 27 June 2022, see https://www.nuclearelectrica.ro/2022/06/27/14-million-grant-announced-by-president-biden-for-the-development-of-small-modular-reactors-smrs-in-romania/?lang=en, accessed 7 July 2022.

the status of real SMRs in the United States remains the same as a year ago: there is still not a single project under construction and projected costs are still escalating.[1004]

The NuScale design is widely regarded as the closest to deployment in the United States. In 2022, the U.S. Nuclear Regulatory Commission (NRC) announced that it will be issuing a formal design certification; it had issued a final safety evaluation report in 2020.[1005] Even as it made this announcement about the design certification, the NRC identified many issues that were not resolved. Important among them was the stability of the steam generator,[1006] a concern that was identified in the March 2020 letter from the NRC's Advisory Committee on Reactor Safeguards (see WNISR2020 for more details).[1007]

The design certification is for a 50 MW(e) design. The design that NuScale is planning to build in all the first projects that are under discussion—specifically, the ones proposed for Idaho in the United States, the Doicesti site in Romania, and the Kozloduy site in Bulgaria—is 77 MW per module.[1008] The output had already been increased several times.[1009] Before construction can proceed, however, NuScale needs to get further regulatory approval from the NRC, namely a Standard Design Approval (SDA); currently, NuScale announced that "submittal of the [SDA] application is planned for the fourth calendar year quarter of 2022".[1010]

The first NuScale project proposed to be constructed in Idaho with electricity to be purchased by Utah Associated Municipal Power Systems (UAMPS) has officially updated its plan "from 12 NuScale Power Modules to 6 modules",[1011] which together will produce 462 MW (gross) of electricity. UAMPS described this new output as providing an "easier path to 100% subscription".[1012] The challenge to subscription is evidently the result of the withdrawal of eight

1004 - There is, however, a big billboard advertising the Carbon Free Power Project from UAMPS in Idaho. See UAMPS, "Clean Energy News—CFPP Project Director Dr. Shawn Hughes Reported the Following Activities to the Project Management Committee on April 19", April Carbon Free Power Project Update, 23rd Edition, 27 April 2022, see https://www.uamps.com/file/4e8988aa-2245-4579-ae2a-9c525b4cf996, accessed 7 August 2022.

1005 - Larry Pearl, "NRC to certify NuScale small modular reactor design for use in the US", *Utility Dive*, 1 August 2022, see https://www.utilitydive.com/news/nrc-certifies-nuscale-small-modular-reactor-design-SMR-nuclear-us/628519/, accessed 5 August 2022; and *WNN*, "NuScale SMR receives US design certification approval", 1 September 2020, see https://world-nuclear-news.org/Articles/NuScale-SMR-receives-US-design-certification-appro, accessed 1 September 2020.

1006 - For more information see U.S. NRC, "RIN 3150-AJ98—NuScale Small Modular Reactor Design Certification", 10 CFR Part 52, U.S. Nuclear Regulatory Commission, 2022, see https://www.nrc.gov/docs/ML2200/ML22004A005.pdf, accessed 7 August 2022.

1007 - Jessica Sondgeroth, "A Pox on NuScale's SMR Design Certification", *Nuclear Intelligence Weekly*, 15 May 2020.

1008 - 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, both accessed July 2022.

1009 - Ramana, Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors.

1010 - NuScale, "NuScale Power, LLC Letter of Intent Providing the Carbon Free Power Project (CFPP) Combined License Application (COLA) Response to NRC Regulatory Issue Summary 2020-02 and Regulatory Engagement Plan—Carbon Free Power Project (CFPP) Regulatory Engagement Plan", NuScale Power Inc., January 2022, see https://www.nrc.gov/docs/ML2202/ML22028A277.pdf.

1011 - UAMPS, "December Carbon Free Power Project Update", Utah Associated Municipal Power Systems, December 2021, see https://www.uamps.com/File/9ebaf0bf-4d0a-4073-9ba4-c6e63cdc44c4, accessed 7 August 2022.

1012 - UAMPS, "PUET Committee: Carbon Free Technologies", Utah Associated Municipal Power Systems, October 2021, see https://ieefa.org/wp-content/uploads/2022/02/October-2021-UAMPS-presentation.pdf, accessed 7 August 2022.

municipalities from the project in October 2021, ahead of one of the scheduled "off-ramps".[1013] The total subscription, measured in terms of signed power sales contracts, amounted to just 101 MW as of October 2021.[1014]

"In terms of the cost per installed kilowatt, the current estimate for the UAMPS NuScale project is around 80 percent higher than the corresponding figure for the Vogtle twin AP1000 project in Georgia—and this is before the Vogtle costs exploded from US$14 billion to over US$30 billion once construction started."

The withdrawals from the project were partly a result of high costs, with successive escalations, which resulted in a project cost estimate of US$6.1 billion in 2020.[1015] According to the CEO of UAMPS, the "actual all-in estimated cost of the six module/462 MWe project, including financing, inflationary costs, etc., is [US]$5.32 billion".[1016] In terms of the cost per installed kilowatt, the current estimate for the UAMPS NuScale project is around 80 percent higher than the corresponding figure for the Vogtle twin AP1000 project in Georgia—and this is before the Vogtle costs exploded from US$14 billion to over US$30 billion once construction started.[1017]

CONCLUSION

In the past few years, various utilities and other organizations have come up with their estimates of costs of electricity generation from SMRs. The most recent U.S. estimate comes from NextEra Energy and at the Investor Conference 2022, they presented a figure of US$105–135/MWh from new SMRs; in comparison, they estimated "near-firm" (i.e. with four-hour battery storage) wind and solar to cost US$25–32/MWh and US$32–37/MWh respectively.[1018]

Australia's Commonwealth Scientific and Industrial Research Organisation ("CSIRO") came up with a much larger range of estimates, A$136–326 (US$92–220) per MWh.[1019] And in its 2019 Integrated Resource Plan ("IRP"), Idaho Power estimated US$125/MWh for a NuScale plant operating at a 90 percent capacity factor.[1020] The assumption of a 90 percent capacity factor is,

1013 - Sonal Patel, "Shakeup for 720-mw nuclear SMR project as more cities withdraw participation", *POWER Magazine*, 29 October 2020, see https://www.powermag.com/shakeup-for-720-mw-nuclear-smr-project-as-more-cities-withdraw-participation/, accessed 29 October 2020.

1014 - UAMPS, "PUET Committee: Carbon Free Technologies", Utah Associated Municipal Power Systems, October 2021, op. cit.

1015 - UAMPS, "Amended Budget & Plan of Finance", Utah Associated Municipal Power Systems, July 2020, see https://losalamos.legistar.com/LegislationDetail.aspx?ID=4614617&GUID=80F3BB19-BE25-49F0-88CB-2B226422A101&Options=&Search=, accessed 7 August 2022.

1016 - 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 19 December 2021.

1017 - David Schlissel, "Southern Company's Troubled Vogtle Nuclear Project", Institute for Energy Economics and Financial Analysis, January 2022, see https://ieefa.org/wp-content/uploads/2022/01/Southern-Companys-Troubled-Vogtle-Nuclear-Project_January-2022.pdf, accessed 20 January 2022.

1018 - Nextera Energy, Florida Power & Light, et al., "Investor Conference 2022", 14 June 2022, see https://www.investor.nexteraenergy.com/~/media/Files/N/NEE-IR/news-and-events/events-and-presentations/2022/06-14-2022/June%202022%20Investor%20Presentation_Website_vF.pdf, accessed 25 July 2022.

1019 - CSIRO, "Renewables remain cheapest, but cost reductions on hold", Commonwealth Scientific and Industrial Research Organisation, CSIRO, 11 July 2022, see https://www.csiro.au/en/news/news-releases/2022/gencost-2022, accessed 11 July 2022.

1020 - Idaho Power, "Integrated Resource Plan 2019", 2020, see https://docs.idahopower.com/pdfs/AboutUs/PlanningForFuture/irp/2019/2019_IRP.pdf, accessed 17 September 2022.

of course, particularly unlikely if SMRs are used to balance the variability of renewables,[1021] and the cost per unit of electrical energy could be considerably higher.[1022] And because SMRs have been and will be, like large reactors, subject to delays and cost overruns, there is no identifiable scenario under which they could become economical even under the best of circumstances.

1021 - See, for example, D.T. Ingersoll, C. Colbert et al., "Can nuclear power and renewables be friends?", NuScale Power, Energy Northwest, Utah Associated Municipal Power Systems, 3 May 2015, in "Proceedings of ICAPP 2015", International Congress on Advances in Nuclear Power Plants, 3–6 May 2015, see https://www.nuscalepower.com/-/media/Nuscale/Files/Technology/Technical-Publications/can-nuclear-power-and-renewables-be-friends.ashx?la=en&hash=2A0EB3B5CA22BF25F90FF16BA060835A0B2DFDF2, accessed 20 April 2020.

1022 - David Schlissel and Dennis Wamsted, "NuScale's Small Modular Reactor: Risks of Rising Costs, Likely Delays, and Increasing Competition Cast Doubt on Long-Running Development Effort", Institute for Energy Economics and Financial Analysis, February 2022, see https://ieefa.org/articles/ieefa-us-small-modular-reactor-too-late-too-expensive-too-risky-and-too-uncertain, accessed 7 August 2022.

NUCLEAR POWER AND WAR

INTRODUCTION

The invasion of Ukraine has generated a deluge of horrific images of destruction and human suffering. For the first time, we have also witnessed an operating nuclear power plant under attack by tank shelling and eventually being occupied by enemy forces.

This chapter deals with the risks of nuclear power facilities in war situations. It focuses on risks of possible major releases of radioactivity into the environment.

The analysis concentrates on nuclear power plants and spent-fuel storage facilities. WNISR in general does not cover nuclear fuel chain facilities. Also, most of these other nuclear facilities have a much smaller radioactive inventory and therefore have a lower potential for a major release (e.g. research facilities, fuel fabrication plants). Important exceptions are big reprocessing plants, but they are located only in a few countries, notably in France.

In the past, there has been limited literature addressing the effects of war on nuclear power plants and other nuclear facilities. Examples are:

- Bennett Ramberg authored a comprehensive book *Destruction of Nuclear Energy Facilities in War – The Problem and the implications* in 1980.[1023] The analysis deals in particular with the question to what extent nuclear facilities near the front could be used as weapons by the aggressor as well as by the defender, mainly from a political analysis point of view.
- In the 1983 study "Risk Assessments of Light Water Reactors", the technical risks for nuclear power plants in war situations are dealt with in more detail in the chapter "War".[1024]
- In 2015, an article entitled "Nuclear plants in war zones" was published by a Ukrainian nuclear expert.[1025] The piece also contains an analysis of previous war situations.
- In 2017, the study "Nuclear safety in crisis regions" examined the topic from both safety and crisis policy aspects.[1026] Previous wartime situations are also analyzed.

Vulnerabilities of Nuclear Power Reactors and Spent Fuel Pools Due to Decay Heat

Unlike all other types of power plants, the safety of a nuclear power plant depends on continuously functioning cooling systems. The physical reason for this is the radioactive decay of the fission products and transuranic elements produced by neutron capture on uranium. During this decay, considerable amounts of heat are generated, so-called decay heat. If it is not continuously removed by cooling, this leads to strong heat buildup, which can cause melting,

1023 - Bennett Ramberg, "Destruction of Nuclear Energy Facilities in War – The Problem and the implications", 1980, Lexington, Massachusetts, Toronto, *Lexington Books*, D.C. Heath and Company.

1024 - Öko-Institut, "Risikountersuchungen zu Leichtwasserreaktoren – Analytische Weiterentwicklung zur 'Deutschen Risikostudie Kernkraftwerke' – Band II", commissioned by the German Ministry of Research and Technology, 1983.

1025 - Alexey Kovynev, "Nuclear plants in war zones", *NEI* Magazine, 19 March 2015, see https://www.neimagazine.com/features/featurenuclear-plants-in-war-zones-4536247/, accessed 13 July 2022.

1026 - Veronika Ustohalova and Matthias Englert, "Nuclear safety in crisis regions", Öko-Institut, 12 April 2017, see https://www.oeko.de/fileadmin/oekodoc/Nuclear-safety-in-crisis-regions.pdf, accessed 18 July 2022.

fires, or other events that can cause major releases of radioactive materials. During operation and directly after a reactor shutdown, cooling requirements are particularly high.

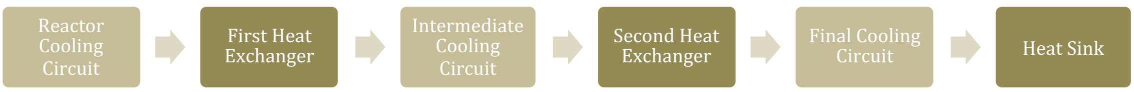
“There is no difference whether the disruption is caused by an accidental event or by deliberate destruction of the reactor cooling system.”

The decay heat generation cannot be stopped and therefore requires continuous cooling even after the reactor has been shut down. The decay heat decreases after nuclear chain reaction has stopped, first rapidly and then more and more slowly as the fission products are a mixture of many nuclides with very different half-lives[1027]. Thus, the remaining decay heat decreases with time, but because of the proportion of fission products with longer half-lives, it is still released for a very long time—for decades —in a significant quantity.

Decay heat is the cause of the melting of a reactor core after a severe disturbance of the reactor cooling. There is no difference whether the disruption is caused by an accidental event or by deliberate destruction of the reactor cooling system.

Immediately after the reactor is shut down from full power, the remaining decay power is almost 7 percent of the thermal reactor power. For a reactor with 1,000 MW of electrical power and thus about 3,000 MW of thermal power, that 7 percent corresponds to heat production of 210 MW. After one day, the decay energy has dropped to about 0.5 percent, which still corresponds to a substantial 15 MW of residual heat to be removed. Furthermore, the residual heat reduces only slowly. After ten days, it amounts to about 0.25 percent. Therefore, even a shutdown reactor must continue to be cooled continuously to prevent overheating.

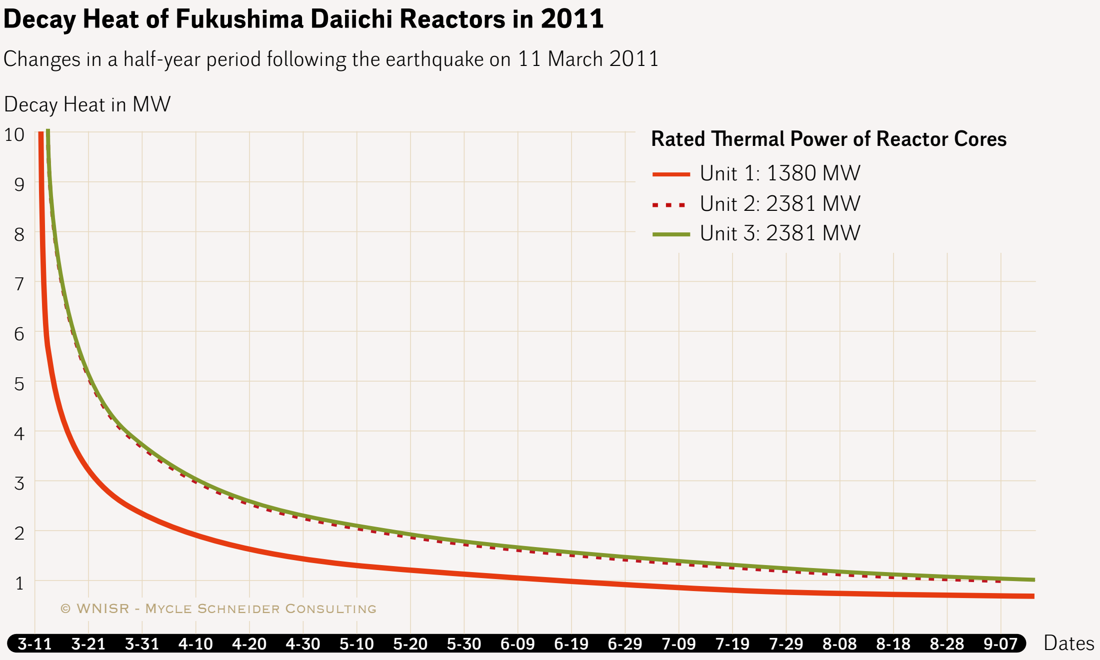
Effective cooling chains must be available with the capacity to dissipate the entire residual heat generated. Such a cooling chain generally has three elements. The first element is a circulation system with which the heated water is pumped out of the reactor system to a heat exchanger (which may combine multiple units) and the cooled water is pumped back into the reactor system. Through the heat exchanger, the residual heat is transferred to a second circuit, the intercooling circuit. The intercooling circuit is required to prevent the direct release of radioactivity into the environment via the heat sink in the event of leakage in a heat exchanger. The intercooling circuit transports the residual heat to a second heat exchanger. There, the final cooling water absorbs the residual heat and transports the absorbed heat to a heat sink. The heat sink can be a nearby large body of water or a cooling tower. Thus, the path of heat removal is:



A functional circulation pump is required for each cooling circuit—thus three pumps in all. Only if these cooling chains are functional and available with the required capacity is successful residual heat removal possible. Otherwise, the reactor core will overheat.

1027 - The time it takes for the radioactivity to lose half of its initial activity by natural decay. Half-lives vary from seconds to millions of years, depending on the specific nuclide.

Figure 47 · Example of decay heat in reactors: Decay heat of the reactors in Fukushima in 2011



Source: TEPCO, May 2011[1028]

Figure 47 shows the residual heat generation over time for the three reactor Units 1–3 in Fukushima Daiichi for the first six months after the accidents (11 March to early September 2011). In the first days the residual heat decreases rapidly. After that, however, the residual heat production decreases only slowly. Residual heat generation is also lower for a smaller reactor (Unit 1, red line) than for larger ones (Unit 2 and 3, green and purple lines).

Those three curves are representative for all nuclear power reactors, as the shape of the curves for other reactors are similar. There are modifications in height primarily depending on their capacity. Smaller additional differences depend on the burnup of the fuel elements (hence their concentration of intensely radioactive fission products), and on the operating history immediately preceding the event. The basic shape of the decay curve, however, is the same, because the operation of all power reactors leads to similar compositions of radioactive fission products that generate the heat. Only their quantities differ.

Spent fuel elements are removed from the reactor at the end of their service life and stored in pools filled with water. The water in the pools must continue to be cooled to remove the residual heat, so a functional cooling chain must also be in place for heat removal from the storage pool.

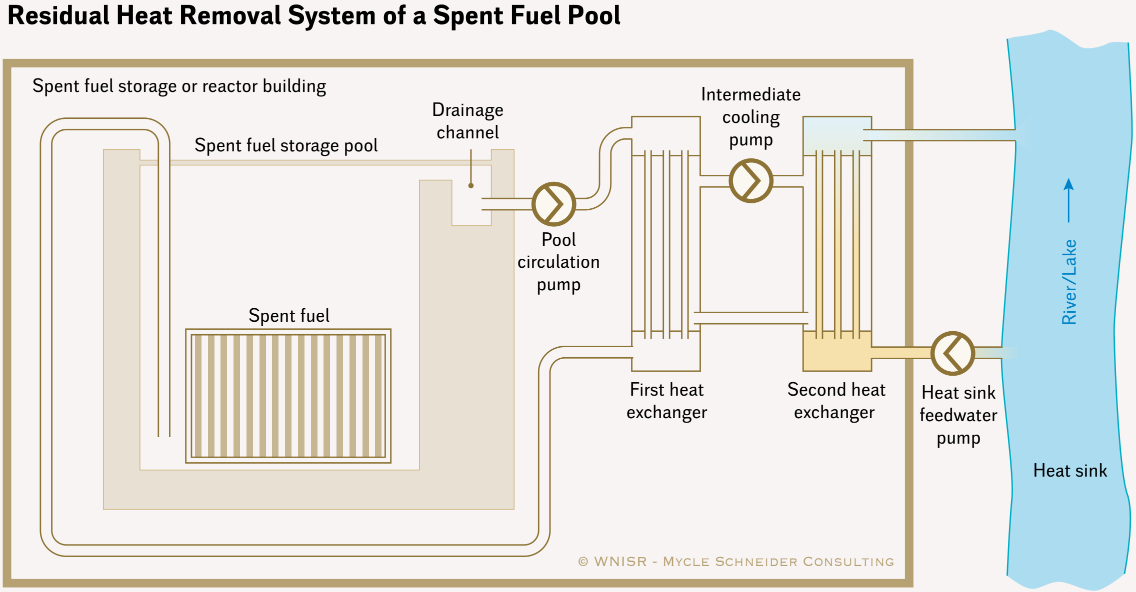
The first link in the cooling chain is a circulation system that pumps the heated water from the storage pool to a heat exchanger. Via the heat exchanger, the residual heat is transferred to a second circuit, which transports the absorbed heat to a heat sink. The heat sink can be a nearby

1028 - TEPCO, "Decay Heat of Fuel in Reactor (changes in half year period after the earthquake)", 26 May 2011, see https://www.tepco.co.jp/en/nu/fukushima-np/images/handouts_110526_01-e.pdf, accessed 18 July 2022.

large body of water or a cooling tower. In many wet storage facilities, a so-called intermediate cooling circuit with a further heat exchanger is located between the two circuits. This results in a heat dissipation along the path of the storage pool cooling circuit → first heat exchanger → intercooling circuit → second heat exchanger → final cooling circuit → heat sink (see Figure 48). A functional circulation pump is required for each cooling circuit. Only if this entire cooling chain is functional is successful residual heat removal possible.

Figure 48 · Spent Fuel Pool Residual-Heat Removal System

Residual Heat Removal System of a Spent Fuel Pool

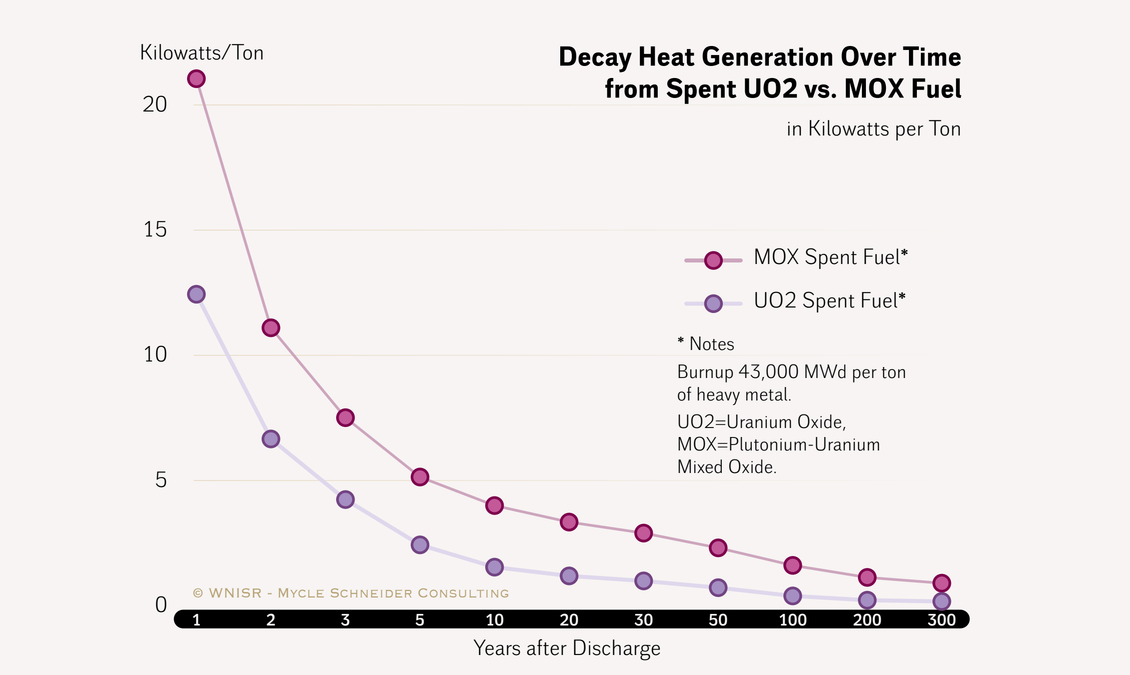


Source: WNISR, 2022.

Figure 49 shows an example of the residual heat output of spent fuel elements in the period from 10 years to 100 years after removal from the reactor. The values of the residual heat are related to one [metric] ton of heavy metal, a measure of the total uranium, plutonium, neptunium, etc. content of the fuel assemblies. Wet storage pools usually contain a few hundred tons of heavy metal, but some pools have a capacity of up to the order of 10,000 tons of heavy metal.

It can be seen from Figure 49 that the residual heat output decreases only slowly over time. Furthermore, it is higher when the burnup of the fuel elements is higher. For MOX (mixed oxide of uranium and plutonium) fuel assemblies, the values are significantly higher (dashed curves). Most wet storage pools contain only uranium fuel assemblies. Some storage pools also contain a proportion of MOX fuel elements. The amount of residual heat to be removed is the sum of the residual heat of the individual fuel assemblies.

Figure 49 · Decay Heat in Spent Low Enriched Uranium and MOX Fuels



Source: Jungmin Kang, 2022[1029]

Many nuclear countries leave their spent fuel elements in such wet storage pools for decades. Eventually, the reactor pools, even if dense-packed, fill up and the oldest (coolest) fuel must be removed to make space for newly discharged spent fuel. However, some countries do have central storage pools. Alternatively, after sufficient reduction of the residual heat generation, the fuel assemblies can be stored in so-called dry storage casks. In these, the remaining residual heat is dissipated to the surrounding air via the outside surface of the storage cannister or cask, optimized for heat dissipation. The surrounding air is guided differently, depending on the design. There are storage facilities with casks located in the open air, in this case no special air guidance is required. In other types, the casks are surrounded by reinforced concrete shielding, in which case the air flows in a gap between the container and the shielding. There are also storage facility types where casks are hosted in a building that has large-volume inlet and outlet openings to guarantee ambient air flow.

Only some countries that use nuclear energy, including the U.S. and Germany, have established such dry storage facilities on a larger scale. Transfer to dry storage casks is possible about three years after the fuel assemblies have been removed from the reactor but is often carried out much later.

The heat that must be removed from fuel assemblies is the same whether they are stored wet or dry, so the conditions in Figure 49 apply to both. The only difference is that dry storage does not need a functioning cooling chain; instead, the residual heat is passively released directly to the surrounding air, which is moved by passive convection (i.e. warmed air rises).

1029 - Jungmin Kang, personal communication, 20 August 2022.

The following section describes wartime risks to nuclear power plants and spent nuclear fuel storage, explores some specific hazards and radioactivity-releasing mechanisms, and concludes with recent experiences from Ukraine.

NUCLEAR POWER PLANTS AND SPENT FUEL STORAGE IN WAR

General Roles

Power Supply in War Times

Nuclear power plants provide an important contribution to electricity supply in a number of countries—in 2021, in eight countries[1030] they generated over one third of their electricity. The attacked country is dependent on the electricity supply continuing which requires both the transmission grid and the power plants for electricity supply. If a country produces a significant share of its electricity in nuclear power plants, many of these must continue to be operated. A precautionary shutdown of a large share of them is practically impossible without significantly or drastically reducing the electricity supply in the country.

In principle, an attacking party has an interest in disrupting the energy supply of the invaded country in the short term to weaken the adversary. In the longer term, however, an occupier must also ensure that the energy supply in occupied territory is functioning, both in terms of resuming production and for general infrastructural supply. The weakening of energy supply and infrastructure has played a significant role in past wars, as did the restoration of infrastructure.

Nuclear power plants, as large electricity production facilities, therefore, play a strategic role. In some countries, including Ukraine, nuclear power plants are operated in complexes, each with multiple reactors. Over half of the electricity in Ukraine was produced by nuclear plants before Russia's invasion, and its 15 reactors are located on only four sites with each hosting between two to six units. Thus, each site represents a significant share of the country's electricity generation infrastructure.

Possible/Supposed Role of Nuclear Power Plants Regarding Nuclear Weapons

Another aspect is the potential role of nuclear power plants in war relating to possible military use of nuclear material for nuclear weapons. Weapons-usable nuclear material is generally considered to be either highly enriched uranium (at least 90 percent of the fissile isotope uranium-235 to be highly efficient and compact, or to at least tens of percent to be practicable) or plutonium in any isotopic composition.[1031]

1030 - Belgium, Bulgaria, Czech Republic, France, Hungary, Slovakia, Slovenia, and Ukraine (55 percent), that is six Eastern and Central European and two Western European countries.

1031 - This has been definitively stated since 1976 by the U.S. nuclear-weapons laboratories' top experts. See e.g. Gregory S. Jones, "Reactor-Grade Plutonium and Nuclear Weapons: Exploding the Myths", Nonproliferation Policy Education Center, Arlington, Virginia, 2018, pp. 21ff. A simple physics explanation is Amory B. Lovins's review article, see Amory B. Lovins, "Nuclear Weapons and Power-Reactor Plutonium", *Nature*, 283:817–823, 28 February 1980, with typographic correction 284:190, 13 March 1980, see https://rmi.org/insight/nuclear-weapons-and-power-reactor-plutonium/, accessed 1 August 2022.

Spent uranium fuel always contains a significant amount of plutonium produced by neutron absorption in uranium. The insinuation that an opponent wants to use nuclear facilities to produce plutonium for weapons purposes is now a common pattern of argumentation that is also used in varying degrees of intensity during conflicts. Such discussions typically underplay the important role of technologies, equipment, technical skills, scientific knowledge, and civilian "cover" required to disguise military activities. Here we focus on nuclear materials.

From a purely technical point of view, the following picture emerges:

The common reactor types run on natural or low-enriched uranium and form plutonium during the fission chain-reaction process. Therefore, spent and even partially spent fuel elements always contain a proportion of plutonium. After removal from the reactor, the fuel assemblies can be subjected to plutonium separation. Highly enriched uranium is not a component of the fuel assemblies of the common power reactors.[1032] However, high-assay low-enriched uranium (HALEU), enriched up to 20 percent, or highly enriched uranium, sometimes exceeding 90 percent of uranium-235, is used in various small research reactors.[1033]

The plutonium produced in power reactors can be separated in reprocessing plants, which are complex technical facilities. Several countries have such facilities on a pilot or commercial scale. Separation of plutonium in smaller quantities sufficient for the manufacture of individual nuclear explosive devices is also possible in a large hot cell—a nuclear laboratory facility with remote handling capability.

Storage facilities for spent fuel elements inevitably contain large quantities of plutonium in spent fuel.

A detailed study of the issues only briefly addressed here was conducted by physicist Victor Gilinsky, a former U.S. Nuclear Regulatory Commissioner.[1034]

The technical context shows that a rationale for an attack on a nuclear reactor may be the intent to eliminate the enemy's potential for producing separated plutonium for nuclear weapons, by destroying, disabling or seizing nuclear power plants, research reactors and interim spent fuel storage facilities—whether the enemy is engaged in or displaying ambitions to develop a nuclear arsenal or not. In the confrontation with both Iraq and Syria, such considerations probably led to the destructive attacks on nuclear reactors in those countries.

The acquisition of necessary radioactive substances to manufacture "dirty bombs" constitutes another potential motive but these are not considered in detail here. The purpose of such a bomb is to spread radioactive materials over large areas without a nuclear chain reaction. In principle, all radioactive substances are suitable for a "dirty bomb", including those from nuclear power plants or spent fuel storage facilities.

1032 - However, there are various types of research and military (chiefly naval) reactors that operate with highly enriched uranium. They are not commercially generating power and are thus outside the scope of this analysis.

1033 - Such materials are proposed to be used in various kinds of "advanced reactors" now under development, with serious nonproliferation implications, see Frank von Hippel, "Perspective: The DOE Ignores History, Risks Proliferation", *Nuclear Intelligence Weekly*, 18 February 2022, see https://www.energyintel.com/0000017e-ff91-df96-a1fe-fffddf990000, accessed 1 August 2022.

1034 - Victor Gilinsky, Marvin Miller and Harmon Hubbard, "A Fresh Examination of the Proliferation Dangers of Light Water Reactors", Nonproliferation Policy Education Center, Working Paper 1701, Updated 1 March 2017, see https://npolicy.org/article.php?aid=172, accessed 15 July 2022.

Fear of an Accident as Political Pressure Tool

Nuclear power plants can release large quantities of radioactive substances after a severe accident, leading to widespread contamination of land. This was demonstrated with the Chernobyl and Fukushima accidents.

Warlike destruction of a nuclear power plant would lead to similar consequences. A warring party could deliberately carry this out to cause significant environmental contamination and economic damage to the opposing country.

In war situations, this can also build up blackmail potential. One side threatens destruction and can put pressure on the other side as the latter has a natural interest in protecting its population and preserving its land uncontaminated.

Diverse constellations of interests and players are imaginable here.

Reasons for Military Action in Nuclear Power Plant Areas

A simple approach would be a declaration that no military action that could endanger the security of nuclear power plants or their infrastructure or staff may take place in or around such plants in wars.[1035] In fact, however, this is wishful thinking.

Occupation of the Area

If an attacker wants to gain control over a given area, they cannot tolerate any points in the area that they do not control. This is because the attacked party could gather people and equipment and launch counterattacks from those positions.

Similarly, if the attacked party makes territorial gains again, it cannot leave any points in the possession of the attacker in the recaptured territory.

Nuclear power plant sites or sites with other nuclear facilities cannot be exempted from this basic principle. This is probably also one of the main reasons why, at an early stage of the war in Ukraine, the Chernobyl site was occupied by Russian military forces.

Destruction of Electric Power Supply

From a military logic point of view, a situation can easily arise in which it would make sense to disable the opponent's electrical power supply to weaken him. In a prolonged war situation, this aspect becomes increasingly important to disrupt or even destroy the enemy's ability to regenerate its resources. This can justify a massive attack on the facilities of a nuclear power

1035 - A similar approach was defined by the IAEA as the "seven indispensable pillars of nuclear safety and security":
1. The physical integrity of the facilities – whether it is the reactors, fuel ponds, or radioactive waste stores – must be maintained;
2. All safety and security systems and equipment must be fully functional at all times;
3. The operating staff must be able to fulfil their safety and security duties and have the capacity to make decisions free of undue pressure;
4. There must be secure off-site power supply from the grid for all nuclear sites;
5. There must be uninterrupted logistical supply chains and transportation to and from the sites;
6. There must be effective on-site and off-site radiation monitoring systems and emergency preparedness and response measures; and
7. There must be reliable communications with the regulator and others.
See IAEA, "IAEA Director General Grossi's Initiative to Travel to Ukraine", IAEA, 4 March 2022, see https://www.iaea.org/newscenter/pressreleases/iaea-director-general-grossis-initiative-to-travel-to-ukraine, accessed 29 August 2022.

plant, but also the destruction of overhead transmission lines that supply power to and distribute electricity from the nuclear power plant. That could trigger reactor meltdowns if the onsite backup generators failed or ran out of fuel, since the equipment for removing residual heat from the shutdown reactors would then lack the electricity to operate.

In a war situation where the attacker assumes being able to easily and quickly overrun the target area, this aspect probably does not play a major role, as they would rather take over an infrastructurally intact territory. However, it is conceivable to consider switching off the power plant as a source of electricity for a limited time and putting it back into operation later, for example by provisionally disrupting important components, e.g. transformers of the power plant or the associated switchyards. Switchyards and powerlines can be temporarily disabled without destroying them, for example, by metal chaff.

Why it is Difficult to Exclude Nuclear Facilities from War

As shown above, in war situations, there is a military rationale why action is considered necessary. According to international treaties, nuclear facilities should not be attacked in principle.[1036] But the complex treaties also contain possibilities for justified exceptions, e.g. if attacks can be launched from the nuclear site. In fact, it can be assumed that military actions will take place on-site in the event of war.

Furthermore, some infrastructure necessary for nuclear safety is located outside the power plant site, from overhead power lines to staff housing, communities in which staff and their families live, and suppliers of necessary materials. If their territory is subject to warfare, this directly threatens the safety of the nuclear power plant.

Intended and Unintended Attacks on Nuclear Safety

The military planning of both sides may specifically plan for an occupation or recapture of a nuclear power plant site. There may also be concrete plans to interrupt power generation.

It cannot be ruled out, especially after a long period of war, that the nuclear power plant will also be destroyed in the sense of "scorched earth", whether by the attacker in retreat, the desperate defender, or irregular fighters out of destructive fury.

However, there may also be direct impacts on nuclear safety that may not be directly intended militarily.

- Weapons used are only accurate to a limited extent and a limited percentage. Destruction of relevant plant components or even the reactor building or spent fuel pool can therefore also occur unintentionally.

1036 - Useful overviews of juridical questions are provided in Tibisay Morgandi and Batuhan Betin, "Legal Implications of the Military Operations at the Chernobyl and Zaporizhzhya Nuclear Power Plants", *EJIL: Talk!*, Blog of the *European Journal of International Law*, 15 April 2022, see https://www.ejiltalk.org/legal-implications-of-the-military-operations-at-the-chernobyl-and-zaporizhzhya-nuclear-power-plants/, accessed 15 April 2022; and Anne Dienelt, "How Are Nuclear Power Plants Protected by Law During War?", *Völkerrechtsblog*, 7 March 2022, see https://voelkerrechtsblog.org/how-are-nuclear-power-plants-protected-by-law-during-war/, accessed 23 August 2022.

- During a combat action, it may appear militarily necessary to direct massive use of weapons against the enemy in certain directions. Collateral damage through the destruction of safety- and security-relevant facilities is then not a focus of attention for the combatants.
- It cannot be assumed that combatants have in-depth knowledge of the safety relevance of individual parts of a nuclear power plant. Even if the operational command were to have such knowledge, it would be extremely difficult or impossible to translate this into practically effective operational instructions. Combatants are therefore usually unable to assess the side effects of their combat actions.
- It can hardly be assumed that in a life-or-death combat situation, those involved are in a position to make subtle calculations about the relevance of their acts for nuclear power plant safety.
- It may also be that involved military units deliberately use the power plant site as a shield against attacks. They then expect the enemy to refrain from attacks on their position because they do not want to create damage to the nuclear facilities. In this way, an impregnable fortress is to be created.

Specific Vulnerabilities of Nuclear Power Plants

Nuclear power plants are complex industrial facilities. Their safe operation depends on a stable environment, as is usually the case in peacetime when normal political and economic conditions prevail. In particular, the operation of nuclear power plants places considerable demands on stable infrastructure.

Previous research on the safety of nuclear power plants has taken these stable circumstances for granted. Only a few published investigations explore nuclear safety in unstable times in general and specifically in a war situation (see Introduction).

However, conclusions about wartime situations can be derived from the many existing studies on randomly occurring severe accidents in peacetime. This is because the effects of system failures in a nuclear power plant are the same, regardless of whether they are triggered by accidental failure or by the effects of war.

Unlike all other types of electricity generating technologies, a nuclear power plant relies on permanently functioning cooling even when they are shut down. During operation and directly after shutdown, the cooling requirements are particularly high and the consequences of failure especially serious.

Direct Destruction

Direct fire (attack with military munitions) can be deliberate to destroy the reactor or necessary safety equipment, or it can hit safety-relevant parts and systems "accidentally" in the course of warfare.

The reactor system and some important safety systems are located in the reactor building. The design of the building varies greatly depending on national regulations and the type of reactor. Some reactor designs offer little more than the structural safety common in other industrial plants with risk potential. This is true for many older reactors. Some of the reactors are designed against the crash of certain types of aircraft, but often can only withstand the impact of a small and slow-flying aircraft. Truly bunkered reactor buildings are found only at a few sites worldwide.

In addition, many important safety systems are located not in the reactor building but in other buildings on the nuclear power plant site. These buildings are generally constructed like other industrial buildings. Only in a very few nuclear power plants worldwide are some of these buildings also of bunkered design for special protection against external influences. Such important safety systems located outside the reactor building include parts of the cooling chains, large parts of the power supply, transformers, diesel generators for emergency power, generator fuel, switchgear, and the control room.

Under wartime conditions, weapons are specifically designed to destroy building structures and are capable of a far greater mechanical impact on the structures of the reactor building than a crashing aircraft. In wartime situations, it is also possible that several projectiles could hit the reactor building successively, increasing overall damage. This applies in any case to deliberate bombardment but cannot be ruled out even in the case of "accidental" shelling. It must also be assumed that the existing systems to retain radioactive materials could be destroyed in the event of a severe accident. This applies in particular to the reactor containment building, which is not designed to withstand the extraordinary impacts of modern weaponry.

Explosive or other military projectiles can destroy reactor cooling lines (and in extreme cases also the reactor vessel itself) to such an extent that large amounts of cooling water are lost. In this case, reactor cooling is no longer possible and rapid heating of the reactor core is unavoidable. The installed emergency cooling systems are not designed for all possible situations involving loss of cooling water. In addition, it must be assumed that the emergency cooling systems themselves and their emergency cooling water supplies could be seriously affected by the impact and therefore would not work.

Some structures outside the reactor building are also vital for cooling and controlling the reactor. Examples include:

- The **control-command** of the reactor's safety systems. Both the control room and the related electrical switchyards are located separately from the reactor building and are structurally comparable to offices or light industrial buildings.
- The **main steam lines** of pressurized water reactors. In many designs, these are routed out of the reactor building together at one point that is poorly protected and thus represents a particular vulnerability.
- The **power supply** required for safety systems (see below).
- Other systems in the **cooling chains** for heat dissipation (see below).

The design of all these systems—developed exclusively for peacetime conditions—assumes only a single destructive event. It is also assumed that the event only occurs at one point and that parallel systems (redundancies) are not affected. After the one-time destructive event, it is subsequently assumed that the personnel and the remaining systems are fully capable of action to control and limit the consequences. These idealized conditions underlying standard safety analyses are unlikely to be met in wartime situations.

Power Supply

The most important requirement for electricity supply is a stable connection to the power grid. This is normally required for the removal of the generated electricity, but when the reactor is shut down, it is required instead to import electricity needed for further safe cooling.

Cooling the core of a shutdown reactor requires large pumps. By design, the required electricity must be generated by the nuclear power plant itself during operation, but after shutdown, it must be fed into the plant from the power grid. If the electricity generated by the operating reactor can no longer be exported due to damage to the switchyard or transmission grid, the operators try to regulate the reactor back to self-consumption power, a procedure also called "island operation". This may or may not succeed.

The self-consumption power of a nuclear power plant is at least many tens of MW, ranging up to about 100 MW. This power mainly runs large pumps: the main circulation pumps, the main feed pumps, and the main cooling water pumps—several of each, operating continuously.

If the power reduction to self-consumption fails, the reactor shuts down and must then depend on some other reliable power supply. If the grid is not available for this purpose, the emergency cooling pumps and the other pumps in the cooling chain must be supplied with electricity from the emergency diesel generators. These diesel generators have a limited output in the range of a few MW, so restarting the reactor is only possible with electricity from the power grid. These emergency generators are not designed and tested for long-term continuous operation. They also have a nontrivial failure rate, and other dependencies described below.

If the power grid is disrupted or destroyed by war, the reactor cannot be restarted until the grid can again steadily supply electricity to the nuclear power plant site. This is because the operation of the main circulation pumps, main feed pumps, and main cooling water pumps is required for the restart of the reactor and thus the availability of the self-consumption power.

A somewhat different situation arises at sites with several reactors. Here, a reactor that is still in operation could also supply the neighboring reactors with electricity for cooling and restarting. However, this option is no longer available when the last reactor on the site is also shut down; then only the grid remains. It also presupposes that the operators, controls, transformers, cables, and switching arrangements needed for these improvisations are all intact and continuously available. Damage to one reactor can force operators to flee so they cannot keep the other reactors in a safe condition.

The facilities for controlling the plant are all dependent on reliable power supply. To be able to control the facilities safely, electricity is therefore also required on a permanent basis, from the facility's own production, the electricity grid, or emergency power systems. This also applies to the lighting of the mostly windowless rooms, and to communications with the outside world.

Wartime loss of power means loss of cooling capability of the reactor cores and loss of control. Soldiers and even their commanders are unlikely to understand these complex safety requirements.

Cooling Water Supply

Heat dissipation requires not only a functioning power supply, but also operational cooling for residual heat removal. The cooling chain from the reactor cooling circuit via intermediate cooling circuits to the final heat sink must function. Only a large body of water can provide the final heat sink—and then only if it is not destroyed or too debris-laden as to block the pump inlets.

The design of these cooling systems is site- and plant-specific. Most nuclear power plants are near a river or the seacoast. Others connect by pipelines to a larger body of water farther away. Loss of cooling water due to the interruption of pipelines or pump failure etc. means loss of reactor cooling capacity.

Reactors need not just their normal cooling systems for routine operation, but also emergency core cooling systems and residual heat removal systems. Their capacity is correspondingly smaller, so they can be powered by the emergency power systems. However, the cooling chain for emergency cooling or for residual heat removal must be intact under all circumstances and must reach its heat sink (body of water, cooling pond, etc.). Destruction of pipelines or other loss of water in a link of the cooling chain due to military action removes the ability to dissipate residual heat.

Other Important Infrastructure

As described, a major safety requirement and burden is the array of emergency diesel generators. These require fuel for continuous operation. The usual supply held on the plant site can run them for a few days, because safety analyses always assume a continuous supply from the surrounding area. In wartime, however, this may be difficult or impossible, and commanders may prioritize fueling their own vehicles and weapons platforms. An interruption of the emergency generators' diesel supply would lead to a loss of residual heat removal. The situation is similar for other operating supplies, e.g. lubricants.

Safe functioning, even when the plant is shut down, includes free road access to the premises. This is necessary to rotate operating staff, who normally work in three daily shifts and who must be rested, healthy, calm, and alert to do their critical jobs safely. Road access is also necessary for the delivery of operating materials and spare parts, and for the access of outside personnel needed for plant inspection and maintenance.

In the event of war, free access may be interrupted. Longer transport connections might have to be maintained, e.g. to the places of residence of the operating personnel and to the places of origin of operating materials or spare parts.

Another relevant infrastructure is external fire departments. As a rule, nuclear power plants have a smaller plant fire department, augmented by nearby fire departments in the event of major fire incidents. In the event of war, the question arises as to whether these fire departments have access to the site and whether these fire departments are even ready for action or are tied up with other firefighting work.

If war causes a radiation release, there is also the question of whether the planned emergency response measures (for the peacetime accident) can be initiated and implemented at all, since these rely on a large-scale intact infrastructure, many participating forces, and willing, skilled personnel in good mental and physical condition.

Skilled Operating Staff

Specially trained personnel are required to operate and monitor the systems; they must also be familiar with all the design details and current conditions in the specific plant.

The reactor operators play a particularly important role as they are in charge of the reactor control room. Their tasks may only be performed after many years of training and approval for the specific plant. This also means that an attacker cannot simply bring in his own personnel and thus operate the plant himself. This applies even to personnel who come from a similar plant or from the plant's designer or builder.

Under peacetime conditions, staff rotation and rest between shifts usually function smoothly, as all standard safety analyses assume.

Under wartime conditions, some boundary conditions change significantly:

- It is unclear whether the personnel can leave the facility at the end of their shift. The reasons for this can be both the danger posed by acts of war on the way home and coercion exerted by the attacker's forces. (Coercive situations have been reported from both Chornobyl and Zaporizhia.)
- The same applies to the arrival of the relief shift.
- This can result in situations where staff is forced to stay onsite far longer than intended. This further heightens stress caused by the threat situation, concerns over family and friends, longer working hours, overtiredness, or lack or insufficiency of life necessities.
- There may no longer be the necessary number and skill range of specialists at the plant.
- When an attacker takes command and enforces it through threats, safety protocols easily take a back seat, as the primary concerns are keeping command, survival of those under threat, and possibly power production at any cost.
- Forcibly detained personnel are highly likely to be deprived of their mobile communication devices; the attacker wants to prevent or at least delay information from reaching the enemy side. Operators therefore cannot communicate their status or needs nor obtain expert advice.
- This also means that the individual, likely traumatized staff members are unable to communicate with their families and friends. Uncertainties about the fate of their families, friends and community, who are possibly also in the war zone, create additional stress.

These boundary conditions create a higher susceptibility to operator error or omission.

After some duration of the war situation, questions of loyalty are sure to arise for the personnel, on the one hand the question of obedience towards the occupier, on the other loyalty towards their own country, but also towards their colleagues, the maintenance of nuclear safety and everything it entails, and towards their families and their safety. These potentially conflicting priorities may bring an employee to very different decisions.

A first question is whether an employee will still come on duty at all, or will the motives to stay away (escape, self-protection from acts of war, protection of family…) prevail?

Another question is: How does an employee behave on the site—at the command of the occupier, or in a secret attempt to undermine efforts of the occupier, and how far would they go?

The intention of the attacker also plays a role. Do they want to take over the facility permanently because it is on their future territory, and do they want to win over the staff for themselves? Or do they rather want to let the situation deteriorate or even destroy the facility to harm the attacked side? Or perhaps both?

Maintenance

A nuclear power plant requires regular maintenance and replacements of wearing parts to function safely. Everyday maintenance is largely the responsibility of the permanent crew of the nuclear power plant, as are the repeated checks of all safety-relevant systems. If the crew is under constant stress, as described above, some of this work may be forgotten, abridged, or omitted. In addition, the quality of this painstaking and highly skilled work almost inevitably declines due to stress and fatigue. The effects will become apparent above all in the medium term as the technical safety condition of the plant continuously declines. The longer the war situation lasts, the stronger these effects will become.

Other problems arise in the area of maintenance:

- Spare parts must be delivered to the site. This requires a functioning order, payment, and transport chain. Also, the spare parts must be available at the supplier’s site.
- Spare parts are partly obtained from foreign suppliers. Here, it matters whether the supplier is even willing to deliver to the nuclear power plant in the war zone and to what extent he is prevented from delivering, e.g., by sanctions.
- Major maintenance work is carried out during the annual shutdown periods. These are usually carried out to a considerable extent by subcontractors. These companies would have to be prepared to come to the nuclear power plant located in the war zone; otherwise this work would have to be cancelled.
- Certain maintenance tasks require specialists from outside the plant. Especially in countries with smaller nuclear infrastructures, that often means personnel from another country. This raises the question of whether such personnel will or may be sent to the affected plant in the event of war. Such constraints would probably mean that some maintenance work would no longer be possible.

Inspection

Inspections are another tool of maintaining the safety of nuclear power plants. These are carried out either by the state supervisory authority and/or by commissioned third parties. To do this, these external persons must first be able to access the plant site. The war situation can be an obstacle in many ways.

As representatives of the state power under war, state supervision will not be allowed into a nuclear power plant occupied by the adversary. This is also likely to apply to third parties unless they have come from the country of the aggressor also in pre-war times. It may also apply to external bodies like the International Atomic Energy Agency (IAEA).

Thus, supervision based on inspections and control is a tool for maintaining safety standards that cannot be applied in war situations.

Conclusion on Vulnerabilities of Nuclear Power Plants

Nuclear power plants are immediately vulnerable in war situations. This is directly due to the constant and permanent need for cooling. Extensive failure of the necessary electrical power or destruction of the cooling systems would lead to overheating of the reactor core. It is relatively unimportant whether this damage is intentional, unintentional, or of indeterminate cause and motivation.

On the other hand, with increasing duration, the specific stress on the personnel and poorer maintenance worsens the operating conditions which also increases the probability of triggering serious accidents.

Specific Vulnerabilities of Spent Fuel Storage Facilities

Spent fuel elements are generally removed from the reactor during an annual (or somewhat less frequent) refueling interval. Because of their decay heat, they must remain cooled continuously. In principle, this is done either in wet or dry storage.

Wet storage facilities are water-filled storage pools in which the decay heat is dissipated via a cooling chain into a heat sink (ordinarily, an external body of water) by continuously circulating the heated water. Such wet storage facilities are present in all nuclear power plants, either in the reactor building or in the immediate vicinity in a separate building. Fuel elements that have been removed from the reactor are always stored in a pool first for cooling, radiological shielding, and access prevention. Because of many short-lived radioisotopes, these recently discharged fuel assemblies generate by far the greatest heat of any fuel outside the reactor vessel itself.

In some cases, several reactors will share a joint wet storage facility that, ordinarily will have significantly larger radioactive inventories than the pool of a single reactor.

Dry storage facilities are sites where casks loaded with spent fuel elements are located. Spent fuel elements can only be transferred to such storage casks after a decay period of several years. Some types place the casks outdoors, others in storage halls ranging from relatively light buildings to massive structures.

Cooling in dry storage facilities is achieved by heat dissipation from the storage container surface to the ambient air ("passive cooling"). Dry storage buildings must therefore be designed to let the ambient air flow through unhindered. Damage to one cask should not normally damage others but may make them inaccessible due to radioactive contamination.

Direct Destruction

Direct fire of a spent fuel storage can be caused deliberately with the aim of destroying the facility or can be triggered by an "accidental hit" in the course of warfare.

Wet storage facilities have a concrete pool surrounded by a building. Insofar as the wet storage facility is located in the reactor building, the degree of protection against bombardment is similar to that of the reactor itself, though without the reactor's own steel vessel. It should also be noted here that the level of protection of the reactor buildings against severe external impacts varies greatly between reactor designs. So does the level of protection of wet storage facilities in separate buildings.

In the case of wet storage, the main hazards are:

- Devices somewhere in the cooling chain could be destroyed so the heat could no longer be dissipated. The cooling water would gradually evaporate. Depending on the quantity and age of the fuel, uncovering the fuel in typically days or weeks.
- The storage pool itself could be destroyed. If it were destroyed, the fuel elements would be left in a disorderly pile and the pool water would escape. The coolant is thus lost. The fuel elements would probably self-ignite and release a very large share of their radioactive inventories.

In the case of dry storage facilities, a direct hazard results from massive bombardment that destroys some containers or casks. The power necessary to penetrate the container or to create major destruction depends on the container design, including materials, geometry, and wall thickness. Tests show that, in principle, a massive storage container can be penetrated with modern weapons such as portable anti-tank missiles, which are designed to pierce up to about a meter of superstrong armor plate. However, the fuel inside would have to be ignited for there to be a major release of radioactivity.

If the dry storage facility has additional building structures (hall walls, shielding, etc.), these result in a certain weakening of the impact if they lie in the path of a projectile fired from outside. In this case, a stronger impact is required to reach and penetrate the container.

Power and Cooling Water Supply

Both types of spent fuel storage depend on electricity for monitoring. In both cases, however, there are longer time periods until non-indicated changes in the system can have a significant effect on safety.

The cooling system of wet storage facilities depends on electricity that can come from the power grid, from reactors onsite, or from an emergency generator. In principle, the failure conditions of electricity supply in wartime are similar to those discussed above for reactors.

However, the water volume in the storage pool and the lower residual heat production compared to the reactor core result in significantly longer grace times. These are shortest in a wet storage facility receiving very hot fuel assemblies freshly unloaded from the reactor. If only fuel assemblies several decades old are stored, grace periods become very long (on the order of months). If the impact of war leads to the leakage or loss of the storage pool water, or inability to replace it with normal or improvised makeup water, the grace periods are significantly reduced.

In addition to the power supply, an intact cooling chain is also required to transfer residual heat from the storage pool water via heat exchangers to a heat sink such as an outside water body. Destruction at any point in the cooling chain would interrupt cooling until it is restored.

A failure of the power supply or the cooling chain over several days is therefore a cause for concern.

The cooling of dry storage facilities, on the other hand, is not dependent on a power supply and active cooling chains due to its passive system design.

Skilled Operating Staff

Skilled personnel are also required at spent fuel storage facilities. Their tasks focus on monitoring and maintenance. In the case of wet storage facilities, the cooling chain must be kept functioning. Here too, staff are similarly affected by the effects of war, as discussed above for reactors. But the smaller scope of the tasks and the much longer grace periods moderate the risk from personnel errors.

Possible Release Mechanisms and Scenarios

Operating Nuclear Power Plant

In an operating nuclear power plant, the residual heat generation is so high that the lack of removal leads directly to core meltdown. How long it takes for core meltdown to occur after cooling failure depends on the specific reactor design, the exact current radioactive inventory, and especially the water content of the relevant systems. Studies of core-melt accidents calculated the delay until the start of meltdown ranging from significantly less than one hour to several hours.

In addition, during a core meltdown, free hydrogen is formed at an early stage, which can explode under appropriate conditions (see events at Fukushima) and can significantly damage the reactor building (see Fukushima). Reactor safety studies also identified other mechanisms that can have an explosive effect (steam explosion from e.g. molten fuel dropping into water, or rapid chemical oxidation reactions).

Physics do not change under wartime conditions. If a core meltdown is triggered by the impact of weapons on the reactor building, more radioactivity is likely to escape because a damaged reactor enclosure cannot fulfil its intended containment purpose.

The core meltdown releases parts of the radioactive inventory into the environment. This can happen within hours of the start of the core meltdown. The quantities are sufficient to severely contaminate extensive areas around the nuclear power plant for decades, requiring relocation of the resident populations. Which areas are most affected depends on the weather conditions. Also, the staff can be affected.

As to the amount of radioactivity released, a wide range is possible, depending on the retention effect of building structures, the level of damage to the structures, and what mitigating measures by operating staff are carried out in time. Under wartime conditions, the upper end of the release range is probably to be expected. Heroic actions may not be effective or even possible.

In principle, the procedures apply to reactors in full-load operation as well as in partial-load operation. It is noteworthy that even a reactor that only generates its own demand is in part-load operation and not shut down. It will therefore continue to generate more fission products.

Shutdown Nuclear Power Plant

A core meltdown is also possible when the reactor is shut down. However, the delay between cooling failure and core meltdown increases. The longer the reactor has been shut down, the less residual heat is produced (see Figure 47). In principle, however, a core meltdown in a reactor that has only been shut down for a few days or weeks can still lead to widespread contamination in the surrounding area.

Pool Storage

When the pool of a wet storage facility loses its cooling function, the water in the pool heats up and stays hot so long as more heat is added than removed. To do their job, the storage pools often contain the spent fuel elements accumulated from many reactor-years of operation. This results in a considerable heat production in total. The proportional contribution of the fuel assemblies that have only been unloaded for a short time is higher, in accordance with the decay curves shown above (see Figure 47 and Figure 49).

The integral heat production must be seen in relation to the available cooling water. The larger the heat added and the smaller the amount of cooling water, the faster the cooling water evaporates, until the fuel elements stand partly or wholly uncovered. No longer immersed in water, they then continue to heat up, become increasingly leaky, and release volatile and semi-volatile radionuclides into the atmosphere above the storage pool. In the temperature range of 800°C, hydrogen formation also starts through chemical reaction of the fuel tube cladding, which on the one hand increases the radioactivity release because of the now more severely damaged tubes and on the other hand releases an explosive substance in the form of hydrogen that in turn could react as well. This occurs in parallel for all fuel assemblies in the affected pool. Also, around 800˚C, the zirconium metal that is typically the main component of the cladding (a tube containing the fuel pellets) can catch fire in air.[1037] Without the cladding, and with the fire's extra heat (in turn igniting more zirconium), more radioactivity escapes.

Under these conditions, volatile and semi-volatile radioactive substances are released from the fuel elements in large quantities. These will enter the immediate and wider environment and cause widespread contamination.

The timescale of these processes ranges from days to many weeks, depending on the specific ratio of residual heat generation and water inventory. The time sequences accelerate

1037 - Frank N. von Hippel and Michael Schoeppner, "Reducing the Danger from Fires in Spent Fuel Pools", *Science & Global Security*, 1 September 2016, see https://www.tandfonline.com/doi/full/10.1080/08929882.2016.1235382, accessed 17 July 2022.

significantly when war- induced destruction lets water escape from the storage pool, eliminating the time buffer of slow evaporation.

"How successful is intervention under war conditions?"

Only after many years of decay of the fuel element inventory in a wet storage facility will a state be reached in which the residual heat is so low that, in case of loss of cooling, the pool water only warms without substantially faster evaporation. Only then would a mere failure of the cooling chain have no further consequences—though severe mechanical impacts could still lead to releases.

Because the heating is relatively slow (compared to a nuclear reactor core), releases could be limited by intervention; but how successful is intervention under war conditions?

In the case of a wet storage facility located directly in a reactor building, the question also arises as to how the conditions in the reactor and in the wet storage pool caused by war damage could influence each other.

Dry Storage

In dry storage facilities, only the destruction of container integrity can cause war-induced radioactivity releases. Casks remaining undamaged release no radioactivity. In the dry storage facility, the fuel assemblies are tightly packed in the individual casks. However, the casks themselves are spaced at greater intervals. This results in a lower overall density of heat compared with a wet storage facility. This geometry also reduces the potential for strong heating.

Factors affecting the size of release include:

- **The opening in the cask created by the destruction.** Less can be released through a mere hole in the container wall than from a cask broken in pieces.
- **Incorporated mechanical energy.** The impact of a weapon can lead to the disintegration of part of the fuel-assembly inventory into aerosol-sized particles.
- **Incorporated thermal energy.** Insofar as the effects of war lead to fire in or around damaged containers, this energy component contributes to heating and thus to the increased discharge of radioactive substances.
- **Intensity of residual heat removal by the ambient air.** It influences the temperature of the affected fuel elements; lower temperatures lead to less release.

Overall, noticeable releases of radioactive substances into the immediate vicinity can be expected from destroyed containers at a dry storage facility—more if munitions cause the spent fuel to shatter or burn.

TIMELINE: WAR IN UKRAINE

The risks described in this chapter are so far theoretical, but situations that could make them real are not far beyond some recent events reported from Ukraine and summarized next. It should be noted that the preceding text has been drafted in May 2022. It is striking to what extent—reportedly—many of the theoretical assumptions have turned into reality in the following months.

In a war situation, it is particularly difficult to verify whether certain reports cover indisputable facts, are exaggerated, or false. The warring parties, as well as organizations and individuals interacting with them, have an interest in a representation that is not necessarily objective.

We have therefore refrained from attempting an objective account of what is happening in Ukraine with and at nuclear facilities. Nevertheless, some insight into the developments should be provided. Therefore, we have compiled the timeline below. It is based exclusively on two sources—the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) and the International Atomic Energy Agency (IAEA). Neither are neutral in this conflict, a situation requiring appropriate caution. Some of these statements have been shortened but all quotations are reproduced here without any modification, including to correct any seeming or obvious inconsistencies in wording, spelling, or grammar.

In addition, there have been various media reports about the situation of the staff in the Ukrainian nuclear power plants in the context of war. Some are in part based on site visits and local interviews. Again, while these investigations have been carried out by esteemed media outlets, it is impossible to independently assess many of the assertions. Such media reports include:

- *France Info*, “Guerre en Ukraine : un employé de Tchernobyl raconte l’occupation russe et les négociations pour sauver la centrale nucléaire” [“War in Ukraine: a Chornobyl employee describes the Russian occupation and the negotiations to save the nuclear power plant”], 13 April 2022.[1038]
- *Atomwirtschaft*, “Nuclear Threat Resulting from Russian Military Occupation of Chornobyl Exclusion Zone”, May 2022.[1039]
- *Energy Intelligence*, “Ukraine: Regulator Describes ‘Terrorism’ at Zaporozhye”, 24 June 2022.[1040]
- *Ukrayinska Pravda*, “Nuclear Threat Resulting from Russian Military Occupation of Chornobyl Exclusion Zone”, 26 June 2022.[1041]

1038 - Camille Magnard and Laurent Macchietti, “Guerre en Ukraine : un employé de Tchernobyl raconte l’occupation russe et les négociations pour sauver la centrale nucléaire”, *Franceinfo*, 13 April 2022 (in French), see https://www.francetvinfo.fr/monde/europe/manifestations-en-ukraine/temoignage-guerre-en-ukraine-un-employe-de-tchernobyl-raconte-loccupation-russe-et-les-negociations-pour-sauver-la-centrale-nucleaire_5079598.html, accessed 16 July 2022.

1039 - Anatolii V. Nosovskyi, Vyacheslav M. Shestopalov, et al., “Nuclear Threat Resulting from Russian Military Occupation of Chornobyl Exclusion Zone”, *atw • International Journal for Nuclear Power,* Vol. 67 , Issue 4, as distributed on *yumpu.com*, May 2022, see https://www.yumpu.com/de/document/read/66806990/atw-international-journal-for-nuclear-power-032022/36, accessed 16 July 2022.

1040 - Phil Chaffee, “Ukraine: Regulator Describes ‘Terrorism’ at Zaporozhye”, *Energy Intelligence*, 24 June 2022, see https://www.energyintel.com/00000181-910f-d7da-adc1-976f35b80000, accessed 16 July 2022.

1041 - Olena Roshchina, “A missile flew critically low above the South Ukraine Nuclear Power Plant – Energoatom”, *Ukrayinska Pravda*, 26 June 2022, see https://www.pravda.com.ua/eng/news/2022/06/26/7354746/, accessed 16 July 2022.

→ *The New York Times*, "Using Nuclear Reactors for Cover, Russians Lob Rockets at Ukrainians", 1 August 2022.[1042]

TIMELINE

Note: This is a selection of official statements in chronological order by the International Atomic Energy Agency (IAEA) and the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU).

IAEA **24 February 2022** · IAEA Director General Statement on the Situation in Ukraine[1043]

The International Atomic Energy Agency (IAEA) is following the situation in Ukraine with grave concern and is appealing for maximum restraint to avoid any action that may put the country's nuclear facilities at risk, Director General Rafael Mariano Grossi said today.

In line with its mandate, the IAEA is closely monitoring developments in Ukraine with a special focus on the safety and security of its nuclear power plants and other nuclear-related facilities, he said.

(…) The Director General stressed that the IAEA General Conference – the annual gathering of all the organization's Member States – adopted a decision in 2009 saying "any armed attack on and threat against nuclear facilities devoted to peaceful purposes constitutes a violation of the principles of the United Nations Charter, international law and the Statute of the Agency".

SNRIU **25 February 2022** · Updated information · radiation situation in exclusive zone[1044]

As previously reported, the control levels of gamma radiation dose rate in the [Chernobyl] Exclusion zone were exceeded.

Experts of the Ecocenter connect this with disturbance of the top layer of soil from movement of a large number of radio [sic] heavy military machinery through the Exclusion zone and increase of air pollution.

The condition of Chernobyl nuclear facilities and other facilities is unchanged.

IAEA **2 March 2022** · Update 6 · IAEA Director General Statement on Situation in Ukraine[1045]

Russia has informed the International Atomic Energy Agency (IAEA) that its military forces have taken control of the territory around Ukraine's Zaporizhzhya Nuclear Power Plant (NPP), Director General Rafael Mariano Grossi said today.

In an official letter to the Director General dated 1 March, the Permanent Mission of the Russian Federation to the International Organizations in Vienna also said personnel at the plant continued their "work on providing nuclear safety and monitoring radiation in normal mode of operation. The radiation levels remain normal."

Earlier on 1 March, Ukraine informed the IAEA that all its nuclear power plants remained under the control of the national operator. In an update this morning, the State Nuclear Regulatory Inspectorate of

1042 - Andrew E. Kramer, "Using Nuclear Reactors for Cover, Russians Lob Rockets at Ukrainians", *The New York Times*, 1 August 2022, see https://www.nytimes.com/2022/08/01/world/europe/ukraine-south-counteroffensive-nuclear.html, accessed 1 August 2022.

1043 - IAEA, "IAEA Director General Statement on the Situation in Ukraine", International Atomic Energy Agency, Press Release 9/2022, 24 February 2022, Updated 13 March 2022, see https://www.iaea.org/newscenter/pressreleases/iaea-director-general-statement-on-the-situation-in-ukraine, accessed 18 July 2022.

1044 - SNRIU, "Updated information – radiation situation in exclusive zone", State Nuclear Regulatory Inspectorate of Ukraine, 25 February 2022, see https://snriu.gov.ua/en/news/updated-information-radiation-situation-exclusive-zone, accessed 18 July 2022.

1045 - IAEA, "Update 6 – IAEA Director General Statement on Situation in Ukraine", Press Release 15/2022, 2 March 2022, see https://www.iaea.org/newscenter/pressreleases/update-6-iaea-director-general-statement-on-situation-in-ukraine, accessed 18 July 2022.

Ukraine (SNRIU) said it maintained communications with the country's nuclear facilities and that the NPPs continued to operate normally.

The Zaporizhzhya plant is the largest of Ukraine's NPP sites with six out of the country's 15 nuclear energy reactors. (...)

The Director General has repeatedly stressed that any military or other action that could threaten the safety or security of Ukraine's nuclear power plants must be avoided. He also said that operating staff must be able to fulfil their safety and security duties and have the capacity to make decisions free of undue pressure. (...)

SNRIU **4 March 2022** · 06:00 · Information Notice on Zaporizhzhia NPP Status[1046]

On 4 March 2022, at about 01:00, the shelling of the Zaporizhzhia NPP site by the military forces of the Russian Federation started, what resulted in fires on the ZNPP site.

ZNPP power units remain intact, unit 1 reactor compartment auxiliary buildings have been damaged, which does not affect the safety of the unit. The systems and components important to the safety of the NPP are operational.

At present, no changes in the radiation situation have been registered. (...)

State of the power units:

- Unit 1 is in outage.
- Units 2, 3 cooling of nuclear installations.
- Unit 4 is in operation at 690 MW power.
- Unit 5, 6 cooling of nuclear installations.

SNRIU **4 March 2022** · 15:00 · Updated information about Zaporizhzhia NPP[1047]

The largest nuclear power plant in Europe, Zaporizhzhia NPP, was captured by the military troops of the Russian Federation after heavy fighting in the streets of Energodar.

As a result of artillery shelling of the ZNPP industrial site:

- the reactor compartment building of the ZNPP unit 1 was damaged;

- 2 artillery shells hit the area of the dry type spent nuclear fuel storage facility.

The degree of damage to the structures and systems of these nuclear installations and their impact on safety requires additional assessments based on the results of the comprehensive inspections by the special services of the Operating Organization.

The fire, which broke out at night due to the enemy shelling of the ZNPP industrial site, severely damaged the training center building located in the immediate vicinity of the ZNPP industrial site.

Operational personnel, who were on shift at the time of the Russian occupation of the ZNPP site, were forced to continue working at their workplaces for more than 24 hours. There are no killed or injured ones among the ZNPP personnel. Some of the personnel received medical care due to stress.

1046 - SNRIU, "Information Notice on Zaporizhzhia NPP Status (04 March 2022, 06:00)", 4 March 2022, see https://snriu.gov.ua/en/news/information-notice-zaporizhzhia-npp-status-04-march-2022-0600, accessed 18 July 2022.

1047 - SNRIU, "Updated information about Zaporizhzhia NPP (15:00)", 4 March 2022, see https://snriu.gov.ua/en/news/updated-information-about-zaporizhzhia-npp-1500, accessed 18 July 2022.

IAEA **6 March 2022** · Update 13 · IAEA Director General Statement on Situation in Ukraine[1048]

Ukraine informed the International Atomic Energy Agency (IAEA) today that although regular staff continued to operate the Zaporizhzhya Nuclear Power Plant (NPP), the plant management is now under orders from the commander of the Russian forces that took control of the site last week, Director General Rafael Mariano Grossi said.

Furthermore, Ukraine reports that any action of plant management – including measures related to the technical operation of the six reactor units – requires prior approval by the Russian commander.

The Director General expressed grave concern about this development as it contravenes one of the seven indispensable pillars of nuclear safety and security that he outlined at the meeting of the IAEA's Board of Governors on 2 March, convened to address the safety, security and safeguards implications of the situation in Ukraine.

Pillar 3 states: "The operating staff must be able to fulfil their safety and security duties and have the capacity to make decisions free of undue pressure".

In a second serious development, Ukraine has reported that the Russian forces at the site have switched off some mobile networks and the internet so that reliable information from the site cannot be obtained through the normal channels of communication. (…)

In one positive development, operational teams at the plant were now rotating in three shifts. But there were problems with availability and supply of food, which was having a negative impact on staff morale, the regulator said.

The regulator also reported that it was facing problems communicating with personnel at the Chornobyl NPP, which at the moment was only possible with e-mails. Russian forces took control of the site of the 1986 accident on 24 February. At the Chornobyl NPP, the staff of more than 200 technical personnel and guards have still not been able to rotate since 23 February, it said.

Director General Grossi has repeatedly stressed the importance of operating staff being able to rest to carry out their important jobs safely and securely.

"I call on those in effective control of the Chornobyl NPP to immediately allow staff there to rotate for the sake of safety and security," he said.

In another concerning development, communications have also been lost with all enterprises and institutions in the port city of Mariupol that use Category 1-3 radiation sources and there was no information about their status, the regulator said. Such radioactive material can cause serious harm to people if not secured and managed properly. (…)

SNRIU **7 March 2022** · Updated information about Zaporizhzhia NPP (ZNPP)[1049]

As of 10:00, 2 units of the Zaporizhzhia NPP (ZNPP) are connected to the grid. One unit is under preventive maintenance and the others are shut down.

On 6 March 2022 at 16:06, the 750 kV high-voltage line was damaged and thus disconnected in the area of Vasylivka, Zaporizhia region, during fierce fighting.

According to management of ZNPP, which is under control of Russian troops, operational personnel monitor the condition of the power units and ensure their safe operation in accordance with the requirements of the operating procedures. (…)

1048 - IAEA, "Update 13 – IAEA Director General Statement on Situation in Ukraine", Press Release 22/2022, 6 March 2022, see https://www.iaea.org/newscenter/pressreleases/update-13-iaea-director-general-statement-on-situation-in-ukraine, accessed 18 July 2022.

1049 - SNRIU, "Updated information about Zaporizhzhia NPP (ZNPP)", 7 March 2022, see https://snriu.gov.ua/en/news/updated-information-about-zaporizhzhia-npp-znpp, accessed 18 July 2022.

The presence of armed enemy troops and heavy equipment on the territory of the Zaporizhzhia NPP and in Energodar creates psychological pressure on both NPP personnel and the population.

There are interruptions with mobile connection in the town, most internet providers do not work and there are food problems. All this has a negative impact on the emotional condition of the NPP staff and significantly affects the assurance of NPP nuclear and radiation safety.

SNRIU **8 March 2022** · 11:00 · Update · ChNPP facilities[1050]

All Chornobyl NPP facilities located in the Exclusion Zone are under the military control of the aggressor country for the thirteenth day in a row, the Chornobyl NPP personnel has been courageously and heroically performing their functions without rotation to ensure the safe operation of the facilities.

Regulatory control over the state of nuclear and radiation safety at the Chornobyl NPP site and in the Exclusion Zone is currently impossible to exercise.

Operation of the Automated Radiation Monitoring System of the Exclusion Zone has not been restored yet.

According to the information received from the Chornobyl NPP personnel through available communication channels, safety parameters of the Chornobyl NPP facilities are still within the standard limits.

Stationary and cellular telephone connection with the Chornobyl NPP personnel currently working at the NPP site, has not been restored.

Railway and motor traffic with the Chornobyl NPP have not been restored.

Operation of the high-voltage line HVL-330 "Lisova" has not been restored either.

Scheduled activities, maintenance and repair of systems and equipment of the Chornobyl NPP facilities, which must be performed by the day-time personnel, is not be performed since 24 February 2022 due to the occupation. In addition, the activities to be performed with the involvement of contracting organizations are not carried out.

SNRIU **12 March 2022** · Zaporizhzhia NPP status update[1051]

Zaporizhzhia NPP and the Enerhodar city are still under the control of Russian military units.

The current state of the power units remains unchanged: two units are in operation; two units are under repair; the rest are in the shutdown mode. Unit 1 outage and emergency repair of unit 6 transformer continue in the scope and using means currently available at the ZNPP in the conditions of the territory occupation by the enemy.

Two 750 kV high-voltage lines (Zaporizhzhia and South-Donbas) are still not connected, measures are being taken to restore the operability of damaged high-voltage lines. This issue is complicated by active hostilities in the areas of the lines damage.

Independent regulatory oversight over nuclear and radiation safety directly at the ZNPP site is currently not carried out due to the potential danger to life and health of the SNRIU state inspectors, as well as due to the damage to inspectors' workplaces as a result of shelling and seizure of the Zaporizhzhia NPP by the occupiers. At the same time, the SNRIU continues to remain in constant contact with the ZNPP.

1050 - SNRIU, "ChNPP facilities, the situation update as of 08 March 2022, 11:00", 8 March 2022, see https://snriu.gov.ua/en/news/chnpp-facilities-situation-update-08-march-2022-1100, accessed 18 July 2022.

1051 - SNRIU, "Zaporizhzhia NPP status update as of 12 March 2022", 12 March 2022, see https://snriu.gov.ua/en/news/zaporizhzhia-npp-status-update-12-march-2022, accessed 18 July 2022.

According to information received from the ZNPP:

- operational personnel monitor the state of power units and ensure their safe operation in accordance with the requirements of the operating procedures;

- the rotation of both operational and day-time personnel is carried out;

- the ZNPP personnel continues carrying out walkdowns to detect and dispose of hazardous items that appeared on the site during the shelling and capture of the Zaporizhzhia NPP by Russian troops;

- the NPP automated radiation monitoring system and the automated radiation situation monitoring system for the control and observation areas operate in regular mode; no changes in the radiological situation at the NPP site or in the control area and observation area have been registered. (…)

IAEA **21 March 2022** · Update 28 · IAEA Director General Statement on Situation in Ukraine[1052]

Ukraine informed the International Atomic Energy Agency (IAEA) that the long-delayed rotation of technical staff at the Chornobyl Nuclear Power Plant (NPP) was completed today, enabling them to go home and rest for the first time since Russian forces took control of the site last month, Director General Rafael Mariano Grossi said.

Ukraine's regulatory authority said about half of the outgoing shift of technical staff left the site of the 1986 accident yesterday and the rest followed today, with the exception of thirteen staff members who declined to rotate. Most Ukrainian guards also remained at the site, it added.

Damaged roads and bridges had complicated the transportation of staff to the nearby city of Slavutych, the regulator said. The staff had been at Chornobyl since the day before Russian forces took control of the site on 24 February. They left after handing over operations to newly arrived Ukrainian colleagues who replaced them after nearly four weeks.

The new work shift also comes from Slavutych and includes two supervisors instead of the usual one to ensure that there is back-up available on the site, the regulator said. An agreement had been reached on how to organize future staff rotations at the NPP, where various radioactive waste management facilities are located, it said. (…)

SNRIU **29 March 2022** · Information on the ZNPP current status[1053]

The Zaporizhzhia NPP and Enerhodar city are occupied by the Russian military units since 4 March 2022. Apart from the aggressor-country military, representatives of the State Atomic Energy Corporation of the Russian Federation "Rosatom" are illegally present at the ZNPP site for a long time, the objective of their stay is unknown.

The ZNPP personnel and their families are under constant psychological pressure due to the presence of hostile military occupiers at the NPP site and in the satellite city, as well as a large number of military vehicles. Cases of detention of the NPP personnel by Russian invaders for interrogation have been registered.

We emphasize that psychological and physical pressure on the NPP personnel and their families significantly increases the probability of personnel error, which in turn can lead to emergencies and accidents [bold in the original].

Two ZNPP units are operating at power, the rest are under repair and in standby mode. (…)

1052 - IAEA, "Update 28 – IAEA Director General Statement on Situation in Ukraine", Press Release 41/2022, 21 March 2022, see https://www.iaea.org/newscenter/pressreleases/update-28-iaea-director-general-statement-on-situation-in-ukraine, accessed 18 July 2022.

1053 - SNRIU, "Information on the ZNPP current status (29.03.2022)", 29 March 2022, see https://snriu.gov.ua/en/news/information-znpp-current-status-29032022, accessed 18 July 2022.

SNRIU **1 April 2022** · Chornobyl NPP facilities, current situation[1054]

According to the information provided by the Chornobyl NPP management, on 31 March 2022, at about 20:00, the russian occupiers left the territory of the Chornobyl industrial site.

The radiation situation at the site and the parameters of the equipment controlled by the operational personnel of the Chornobyl NPP are within the limits set by the respective process procedures of nuclear installations.

Day-time and repair personnel, as well as personnel of contracting organizations are still missing at the Chornobyl site.

Currently, the SNRIU is comprehensively analyzing the possibility of resuming regulatory control over the state of nuclear and radiation safety at the Chornobyl NPP site and in the Exclusion Zone, as well as over the state of nuclear materials.

SNRIU **20 April 2022** · Regarding power units on the sites of Ukrainian NPPs[1055]

Power units at the Khmelnytskiy, South-Ukrainian and Rivne NPP sites are operated in normal mode.

From March 4, 2022, the Zaporizhzhia NPP power units are currently under the control of the Russian occupation forces. After the capture of ZNPP, representatives of Rosatom arrived at the station by illegally crossing the state border of Ukraine.

Representatives of Rosatom, in the presence of the occupying forces, informed the management and staff of ZNPP about the intention to include the Ukrainian NPP in the structure of Rosatom. Subsequently, representatives of Rosatom began to monitor technological and management processes at ZNPP.

Due to the impossibility to independently and objectively carry out state supervision directly on the occupied NPP site, the duties of the Head of the Nuclear Safety Inspectorate at Zaporizhzhia NPP are temporarily assigned to the Director of the Department for Nuclear Safety - Deputy Chief State Inspector for Nuclear and radiation safety of Ukraine.

Representatives of the Russian Federation strictly forbid to carry out photo and video recording on the territory of ZNPP, there are threats (including the use of weapons) against persons who intend to do so.

IAEA **29 April 2022** · 67 – IAEA Director General Statement on Situation in Ukraine[1056]

Ukraine formally informed the International Atomic Energy Agency (IAEA) today about the situation at the Zaporizhzhya Nuclear Power Plant (NPP), which is controlled by Russian forces but still operated by its Ukrainian staff, Director General Rafael Mariano Grossi said.

Ukraine said its nuclear specialists "continue to perform their duties and maintain, as far as possible during the war, the safety of the nuclear facilities" in the country.

Ukraine also said that Rosenergoatom – a unit of Russian state nuclear company Rosatom – had sent a group of nuclear specialists to the Zaporizhzhya NPP, naming eight. It said they demanded daily reports from plant management about "confidential issues" on the functioning of the NPP, covering aspects related to administration and management, maintenance and repair activities, security and access control, and management of nuclear fuel, spent fuel and radioactive wastes.

1054 - SNRIU, "Chornobyl NPP facilities, current situation (April 01, 2022)", 1 April 2022, see https://snriu.gov.ua/en/news/chornobyl-npp-facilities-current-situation-april-01-2022, accessed 18 July 2022.

1055 - SNRIU, "Regarding power units on the sites of Ukrainian NPPs", 20 April 2022, see https://snriu.gov.ua/en/news/regarding-power-units-sites-ukrainian-npps, accessed 18 July 2022.

1056 - IAEA, "Update 67 – IAEA Director General Statement on Situation in Ukraine", Press Release 87/2022, 29 April 2022, see https://www.iaea.org/newscenter/pressreleases/update-67-iaea-director-general-statement-on-situation-in-ukraine, accessed 18 July 2022.

Ukraine separately informed the IAEA today that personnel at the Zaporizhzhya NPP – the country's largest with six reactors – were "working under unbelievable pressure". (...)

IAEA **25 May 2022** · IAEA Grossi at Davos: Nuclear Power, Climate Change and Ukraine[1057]

(...) "You have bystanders, abstainers, analysts and you have problem solvers. You must have people who look at problems practically," Mr Grossi said, describing the IAEA as a problem solver. He said the use of nuclear weapons was "unthinkable" and explained that the IAEA's focus was on avoiding nuclear accidents derived from an attack on a nuclear power plant or the release of radioactive material. Mr Grossi added that the IAEA is seeking to visit Ukraine's Zaporizhzhia Nuclear Power Station, under occupation by Russian forces, to verify that the 30,000 kg of plutonium and 40,000 kg of enriched uranium stored there have not been deviated for other uses. (...)

SNRIU **27 May 2022** · The Public Call of Acting Head of the SNRIU to the International Atomic Energy Agency[1058]

The Public Call of Acting Head of the State Nuclear Regulatory Inspectorate of Ukraine – Chief State Inspector for Nuclear and Radiation Safety of Ukraine to the International Atomic Energy Agency (IAEA).

At night on March 4, 2022, the first in the world history forcible seizure of Zaporizhzhia NPP took place, as a result of shelling of which the armed forces of the russian federation killed three Ukrainian defenders and created unprecedented threats to the nuclear safety of the plant, which could lead to a catastrophe on a planetary scale.

After the seizure of Zaporizhzhia NPP, russian occupation forces – the military, along with representatives of the state russian companies Rosatom and Rosenergoatom - constantly terrorize and directly threaten the lives of the plant personnel and residents of the occupied city of Energodar.

The situation is aggravated by the constant missile attacks of the territory of Ukraine by rf, which, ignoring the possible risks and catastrophic consequences, directs them towards nuclear power plants. Cases of overflights of cruise missiles similar to the "Kalibr" were recorded over the South Ukraine NPP (04/16/2022), Khmelnytskyi NPP (04/25/2022) and Zaporizhzhia NPP (04/28/2022).

These acts of russia's nuclear terrorism take place in the absence of a clear position and effective response from IAEA to Ukraine's numerous appeals on this issue, which is why russian representatives are convinced of their impunity and take even more bold actions and statements. In particular, on May 1, 2022, referring to the "official position of IAEA and the statements of its representatives", the so-called mayor of the occupied city of Energodar, appointed by the Russian military, stated that "the Agency did not record violations of the safe operation of ZNPP".

Moreover, the management of IAEA not only encourages further escalation of ZNPP occupation, but also rebroadcasts the theses of the Kremlin propaganda. In particular, on May 25, 2022, in his speech to the audience of the Davos Economic Forum, IAEA Director General Rafael Mariano Grossi stated that allegedly "30,000 kg of plutonium and 40,000 kg of enriched uranium suitable for the manufacture of nuclear weapons" are stored at the russian-occupied Zaporizhzhia NPP. This is clear evidence that IAEA, represented by its Director General, is under the influence of russian propaganda and does not have reliable information.

The State Nuclear Regulatory Inspectorate of Ukraine categorically refutes the information about the alleged presence of plutonium and enriched uranium stocks at the Zaporizhzhia NPP captured by the

1057 - Michael Amdi Madsen, "IAEA Grossi at Davos: Nuclear Power, Climate Change and Ukraine", Office of Public Information and Communication, IAEA, 25 May 2022, see https://www.iaea.org/newscenter/news/iaea-grossi-at-davos-nuclear-power-climate-change-and-ukraine, accessed 18 July 2022.

1058 - SNRIU, "The Public Call of Acting Head of the SNRIU to the International Atomic Energy Agency", 27 May 2022, see https://snriu.gov.ua/en/news/public-call-acting-head-snriu-international-atomic-energy-agency, accessed 18 July 2022.

russians, and in general in Ukraine, which are suitable for the manufacture of nuclear weapons. It is well known to IAEA, which annually confirms in its Safeguards Implementation Report the fulfillment by Ukraine of its obligations regarding the exclusive peaceful use of nuclear material which is under its control.

We remind the world community that, in pursuance of the 2010 Washington Nuclear Security Summit Communiqué, Ukraine voluntarily disposed of all highly enriched uranium on its territory, which was an outstanding event that largely led to an overall positive assessment of the implementation of the nuclear security summit mechanism.

Neither plutonium nor enriched uranium, which can be used for military purposes, has been and is not stored at Zaporizhzhia NPP. Moreover, it is technically and politically impossible for Ukraine to manufacture and store weapons-grade plutonium or uranium, even in quantities of a few grams, due to the lack of technology and a political ban on its production. It is very sad that the odious lies of russian propaganda are being broadcast at a high level by a top IAEA official. At Zaporizhzhia NPP, as well as at all operating NPPs of Ukraine, nuclear fuel is used in the form of fuel assemblies with an enrichment of up to 5%, which is not suitable for the manufacture of nuclear weapons.

The SNRIU would like to remind, that in accordance with the Resolution of the IAEA Board of Governors GOV/2022/17 dated March 3, 2022 "Implications of the situation in Ukraine for security, physical protection and safeguards", the rf must immediately stop all actions directed against nuclear facilities in Ukraine and return control over all seized nuclear installations to the Ukrainian side. Also, in accordance with paragraph 4 of this Resolution, the Director General of IAEA and the Agency Secretariat were instructed to monitor the situation in Ukraine and report to the Board of Governors on relevant violations and threats to the safety of nuclear facilities in Ukraine.

We call on Mr. Grossi to assist Ukraine in our demands for the immediate withdrawal of russian troops, military equipment and Rosatom personnel from ZNPP site and the city of Energodar, which would be the best guarantee for the safe operation of Zaporizhzhia NPP, as well as to demand to stop shelling the territory of Ukraine with cruise and operational-tactical missiles, since such shelling could potentially lead to a planetary catastrophe, greater in its consequences than Chornobyl and Fukushima accidents altogether.

IAEA **6 June 2022** · Grossi Expresses Concern to IAEA Board about Safeguards in Iran; Nuclear Safety, Security and Safeguards at Zaporizhzhya Nuclear Power Plant in Ukraine[1059]

(…) Mr Grossi emphatically reiterated his determination to lead an expert mission to the plant, saying: "We must find a solution to the hurdles preventing progress at Zaporizhzhya NPP. I will not stop pursuing this and I count on your active support."

He noted that Ukraine's government had last week called on him to lead such a mission, and that the Ukrainian regulator had earlier informed the IAEA that it had "lost control over the facility's nuclear material".

"One clear line of Ukrainian operational control and responsibility is vital, not only for the safety and security of Zaporizhzhya NPP, but also so that IAEA safeguards inspectors are able to continue to fulfil their regular, indispensable verification activities," he said.

Mr Grossi spoke of the dire situation at the plant, the site of which remains under the control of Russian troops. He again pointed out the pressure on Ukrainian staff working at the plant and informed the Board about the concern that some spare parts were not getting to the plant due to supply chain interruptions. "This means now at least five of the seven indispensable pillars of nuclear safety and security have been

1059 - Miklos Gaspar, "Grossi Expresses Concern to IAEA Board about Safeguards in Iran; Nuclear Safety, Security and Safeguards at Zaporizhzhya Nuclear Power Plant in Ukraine", Office of Public Information and Communication, IAEA, 6 June 2022, see https://www.iaea.org/newscenter/news/grossi-expresses-concern-to-iaea-board-about-safeguards-in-iran-nuclear-safety-security-and-safeguards-at-zaporizhzhya-nuclear-power-plant-in-ukraine, accessed 18 July 2022.

compromised," he said referring to the pillars he enumerated at the IAEA's previous board meeting as essential to ensure safe and secure operations of any nuclear power plant. (...)

IAEA **24 June 2022** · Update 82 · IAEA Director General Statement on Situation in Ukraine[1060]

The International Atomic Energy Agency (IAEA) is increasingly concerned about the difficult conditions facing staff at Ukraine's Zaporizhzhya Nuclear Power Plant (ZNPP) and it must go there as soon as possible to address this and other urgent issues, Director General Rafael Mariano Grossi said today.

Director General Grossi said he was continuing his determined efforts to agree, organize and head an IAEA-led international mission to conduct essential nuclear safety, security and safeguards activities at the ZNPP, stressing again that "other considerations should not prevent" it from taking place.

The IAEA is aware of recent reports in the media and elsewhere indicating a deteriorating situation for Ukrainian staff at the country's largest nuclear power plant (NPP), Director General Grossi said.

"The situation at this major nuclear power plant is clearly untenable. We are informed that Ukrainian staff are operating the facility under extremely stressful conditions while the site is under the control of Russian armed forces. The recent reports are very troubling and further deepen my concern about the well-being of personnel there," he said.

The Director General noted that the seven indispensable pillars for ensuring nuclear safety and security in Ukraine that he outlined at the beginning of the military conflict include one stating that NPP staff "must be able to fulfil their safety and security duties and have the capacity to make decisions free of undue pressure". (...)

IAEA **4 July 2022** · Update 85 · IAEA Director General Statement on Situation in Ukraine[1061]

The International Atomic Energy Agency (IAEA) and the Ukrainian operator of the country's Zaporizhzhya Nuclear Power Plant (ZNPP) have restored the remote transmission of safeguards data from the facility after a week-long interruption, Director General Rafael Mariano Grossi said today.

For the second time in a month, the IAEA on 25 June lost the connection to its safeguards surveillance systems installed at ZNPP. The IAEA worked with the operator to fix the problem and the transfer of data resumed on 1 July and has continued over the weekend, the Director General said. The previous time, the connection was lost for nearly two weeks, from 30 May until 12 June. (...)

SNRIU **5 July 2022** · Supply of Spare Parts to Zaporizhzhia Plant 'May Be Exhausted': Ukraine Regulator[1062]

Interview of the Acting Chairman of the State Atomic Energy Regulatory Authority - Chief State Inspector for Nuclear Safety of Ukraine Oleg Korikov to the publication "S&P Global".

The supply of spare parts to the Zaporizhzhia nuclear power plant in Ukraine may soon "be exhausted if we do not refill them," the acting chief nuclear inspector for the Ukrainian nuclear regulator said in an interview in Brussels June 21.

1060 - IAEA, "Update 82 – IAEA Director General Statement on Situation in Ukraine", Press Release 113/2022, 24 June 2022, see https://www.iaea.org/newscenter/pressreleases/update-82-iaea-director-general-statement-on-situation-in-ukraine, accessed 18 July 2022.

1061 - IAEA, "Update 85 – IAEA Director General Statement on Situation in Ukraine", Press Release 119/2022, 4 July 2022, see https://www.iaea.org/newscenter/pressreleases/update-85-iaea-director-general-statement-on-situation-in-ukraine, accessed 18 July 2022.

1062 - SNRIU, "Supply of Spare Parts to Zaporizhzhia Plant 'May Be Exhausted': Ukraine Regulator", 5 July 2022, see https://snriu.gov.ua/en/news/supply-spare-parts-zaporizhzhia-plant-may-be-exhausted-ukraine-regulator, accessed 23 August 2022.

Oleh Korikov, of the State Nuclear Inspectorate of Ukraine, noted that "all plants have spare parts" and that while the 6-GW Zaporizhzhia plant currently had all of the spare parts that it required, there was also at present no way to replenish such parts as the facility is currently controlled by Russia. The parts in question include valves, for example, and consumables that are used during plant operations, he said. (...)

The "situation at Zaporizhzhia remains complicated, ammunition is located directly at the plant, this is entirely unacceptable from a safety perspective, there are more than 50 Russian military vehicles on site at the plant, a lot of explosives are lying around the site of the plant, it is very dangerous," he said. (...)

A "huge amount of infrastructure and manufacturing and production capacity in the country has already been destroyed" by the Russian attack, posing a "serious risk" to the continued supply of spare parts and replacement items to the country's nuclear units, Korikov added.

Korikov also said that Ukrainian nuclear plants were also "under threat of missile attack, there are Russian cruise missiles flying over nuclear plants, including Zaporizhzhia, this creates clear risks of a nuclear accident. (...)

IAEA **9 August 2022** · Update 89 · IAEA Director General Statement on Situation in Ukraine[1063]

Ukraine has informed the International Atomic Energy Agency (IAEA) that a shelling incident on Saturday near the dry spent fuel storage facility at the country's Zaporizhzya Nuclear Power Plant (ZNPP) caused some damage, but that available radiation measurements continued to show normal levels at the site, Director General Rafael Mariano Grossi said today.

According to Ukraine, Saturday's event – which occurred a day after previous shelling damaged the plant's external power supply system – injured a Ukrainian security guard at the ZNPP. It also damaged walls, a roof and windows in the area of the spent fuel storage facility, as well as communication cables that are part of its radiation control system, with a possible impact on the functioning of three radiation detection sensors, Ukraine told the IAEA. But there was no visible damage to the containers with spent nuclear fuel or to the protective perimeter of the facility. (...)

However, the shelling on Friday and Saturday at the ZNPP breached virtually all the seven indispensable nuclear safety and security pillars that the Director General outlined at the beginning of the conflict, including those related to a nuclear power plant's physical integrity, functioning safety and security systems, staff and external power supplies. (...)

IAEA **19 August 2022** · Update 92 – IAEA Director General Statement on Situation in Ukraine[1064]

The Director General of the International Atomic Energy Agency (IAEA), Rafael Mariano Grossi, today renewed his urgent appeal for maximum military restraint in the area of Ukraine's Zaporizhzya Nuclear Power Plant (ZNPP) following new signs of rising tension over Europe's largest such facility. (...)

The Director General made his latest statement today in response to media reports and other information received by the IAEA in recent days indicating possible new nuclear safety and security risks related to the ZNPP, less than two weeks after shelling caused some damage at the plant, including impacting response activities in case of an emergency, that sparked widespread alarm about the situation there. (...)

1063 - IAEA, "Update 89 – IAEA Director General Statement on Situation in Ukraine", Press Release 126/2022, 9 August 2022, see https://www.iaea.org/newscenter/pressreleases/update-89-iaea-director-general-statement-on-situation-in-ukraine, accessed 23 August 2022.

1064 - IAEA, "Update 92 – IAEA Director General Statement on Situation in Ukraine", Press Release 131/2022, 19 August 2022, see https://www.iaea.org/newscenter/pressreleases/update-92-iaea-director-general-statement-on-situation-in-ukraine, accessed 23 August 2022.

SNRIU **22 August 2022** · According to Zaporizhzhia NPP shift supervisor information[1065]

At 02:33 p.m. on August 22, 2022, the russian occupation troops shelled the Zaporizhzhia Thermal Power Plant (Zaporizhzhia TPP).

As a result of the shelling, the RSST -5;6 (reserve station service transformers) were damaged and the the communication line Zaporizhzhia NPP – Zaporizhzhia TPP (VL-330) line was disconnected.

At 06:33 p.m. the operation of the Zaporizhzhia NPP - Zaporizhzhia TPP (VL-330) line was renewed.

Information about the victims is being clarified.

IAEA **7 September 2022** · Update 99 · IAEA Director General Statement on Situation in Ukraine[1066]

Renewed shelling has damaged a back-up power line between Ukraine's Zaporizhzhya Nuclear Power Plant (ZNPP) and a nearby thermal power station, further underlining significant nuclear safety risks at the facility, the International Atomic Energy Agency (IAEA) learnt at the site. (...)

But the damage to the 750/330 kilovolt (kV) line once again demonstrated the difficulties and vulnerabilities the ZNPP is facing when it comes to external power supplies. The ZNPP lost the connection to all its four main external power lines earlier during the conflict, the last one on 2 September. Of the three back-up lines between the ZNPP and the thermal power station, one is now damaged by shelling, while the two others are disconnected, senior Ukrainian operating staff informed IAEA experts present at the plant since last week. (...)

IAEA **11 September 2022** · Update 100 · IAEA Director General Statement on Situation in Ukraine[1067]

„Yesterday evening's restoration of a 330 kilovolt (kV) reserve line – which connects Europe's largest nuclear power plant to the Ukrainian network through the switchyard of a thermal power station in the nearby city of Enerhodar – enabled the ZNPP to shut down its last operating reactor early this morning. This reactor had over the past week provided the ZNPP with power after the facility was disconnected from the grid. With the line restoration, electricity needed for nuclear safety at the ZNPP once again comes from the external grid. (...)

A secure off-site power supply from the grid and back-up power supply systems are essential for ensuring nuclear safety and preventing a nuclear accident, even when the reactors are no longer operating. This requirement is among the seven indispensable nuclear safety and security pillars that the Director General outlined at the beginning of the conflict. (...)

1065 - SNRIU, "State Nuclear Regulatory Inspectorate of Ukraine - According to Zaporizhzhia NPP shift supervisor information", 22 August 2022, see https://snriu.gov.ua/en/news/according-zaporizhzhya-npp-shift-supervisor-information, accessed 23 August 2022.

1066 - IAEA, "Update 99 – IAEA Director General Statement on Situation in Ukraine", 7 September 2022, see https://www.iaea.org/newscenter/pressreleases/update-99-iaea-director-general-statement-on-situation-in-ukraine, accessed 17 September 2022.

1067 - IAEA, "Update 100 – IAEA Director General Statement on Situation in Ukraine", 11 September 2022, see https://www.iaea.org/newscenter/pressreleases/update-100-iaea-director-general-statement-on-situation-in-ukraine, accessed 17 September 2022.

IAEA **13 September 2022** · Update 102 · IAEA Director General Statement on Situation in Ukraine[1068]

"Ukrainian engineers have made further headway in repairing vital power infrastructure in the vicinity of the Zaporizhzhya Nuclear Power Plant (ZNPP), providing the plant with renewed access to a third back-up power line, the International Atomic Energy Agency (IAEA) was informed at the site today.

The 150 kilovolt (kV) back-up line was made available to the ZNPP again after the repair of an electrical switchyard at a nearby thermal power plant, a few days after it was damaged by shelling that also plunged the city of Enerhodar into darkness.

This means that all three back-up power lines to the ZNPP – Europe's largest nuclear power plant – have been restored over the past few days. One of them, a 750/330 kilovolt (kV) line, is now providing the ZNPP with the external electricity it needs for cooling and other essential safety functions. The 330 kV and the 150 kV lines are being held in reserve. All the ZNPP's six reactors are in a cold shutdown state, but they still require power to maintain necessary safety functions. (...)

Despite these developments related to the plant's power situation, Director General Rafael Mariano Grossi again stressed that the nuclear safety and security situation at the plant – held by Russian forces but operated by Ukrainian staff in the middle of a war zone – remained precarious.

1068 - IAEA, "Update 102 – IAEA Director General Statement on Situation in Ukraine", 13 September 2022, see https://www.iaea.org/newscenter/pressreleases/update-102-iaea-director-general-statement-on-situation-in-ukraine, accessed 17 September 2022.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

INTRODUCTION

The past year has been seminal for climate change and energy security, nuclear power, and renewable energy.

In 2021, climate change was high on the political agenda as governments and companies prepared for the 26th meeting of the parties of the United Nations Framework Convention on Climate Change (COP26, UNFCCC) in November. This was to be a vital meeting of the UNFCCC as all parties were expected to review and revise their Nationally Determined Contributions (NDCs), which contain their adaptation and mitigation plans until 2030 and therefore increase their carbon reduction plans. In preparation for COP26, the IEA published a report outlining a strategy for the energy sector to meet the temperature targets of the Paris Agreement and concluded that in their scenario, "by 2050, almost 90% of electricity generation comes from renewable sources, with wind and solar PV together accounting for nearly 70%."[1069] This is a remarkable perspective from the IEA, which in its scenarios has so long systematically underestimated and downplayed the role for renewable energy.

While most countries did increase the ambition on their climate mitigation goals, some for 2030, including the E.U. members, Japan, the U.K. and U.S., others, including China, India, and Russia, agreed to mid-century carbon neutrality targets. Furthermore, a number of sectorial deals were announced, and re-announced, for mitigation and adaption, including the Powering Past Coal Alliance, an agreement to end the financing of international fossil fuels, all of which are likely to accelerate the reduction in the use of gas, coal and oil in the power sector. The IEA went as far as suggesting that a combination of the announcements made before and during COP26 could potentially restrict the increase in global temperatures to 1.8 degrees above pre-industrial levels.[1070] However, this scenario assessment relies very heavily on countries all meeting their short-term goals and the midcentury carbon neutrality plans, which is seen by many as optimistic especially given 2030 mitigation targets are far from being met. According to Climate Action Tracker "without increased government action, the world will still emit twice the greenhouse gas emissions in 2030 than is allowed under the 1.5°C limit of the Paris Agreement. The world is heading to a warming of 2.4°C with 2030 targets and even higher, 2.7°C, with current policies".[1071]

1069 - IEA, "Net Zero by 2050 – A Roadmap for the Global Energy Sector", International Energy Agency, May 2021, see https://www.iea.org/reports/net-zero-by-2050, accessed 6 June 2021.

1070 - Fatih Birol, "COP26 climate pledges could help limit global warming to 1.8 °C, but implementing them will be the key", International Energy Agency, 4 November 2021, see https://www.iea.org/commentaries/cop26-climate-pledges-could-help-limit-global-warming-to-1-8-c-but-implementing-them-will-be-the-key, accessed 10 July 2022.

1071 - Climate Action Tracker, "Glasgow's 2030 credibility gap: net zero's lip service to climate action", 3 June 2022, see https://climateactiontracker.org/publications/despite-glasgow-climate-pact-2030-climate-target-updates-have-stalled/, accessed 24 August 2022.

The invasion of Ukraine has significantly increased the focus on energy security and has highlighted the problems of dependency, especially of a single source, on fossil fuel imports. This has led to further discussions on and interests in non-fossil fuel energy sources including renewable energies and nuclear power. However, as is demonstrated in this chapter, renewables outcompete nuclear power and in fact fossil fuels in the majority of markets as they are cheaper and faster to build and ultimately produce less expensive power. Consequently, more investment is taking place in renewables, which leads to lower prices and more deployment experience, creating a virtuous circle in which renewables are becoming cheaper than all other forms of electricity generation.

INVESTMENT

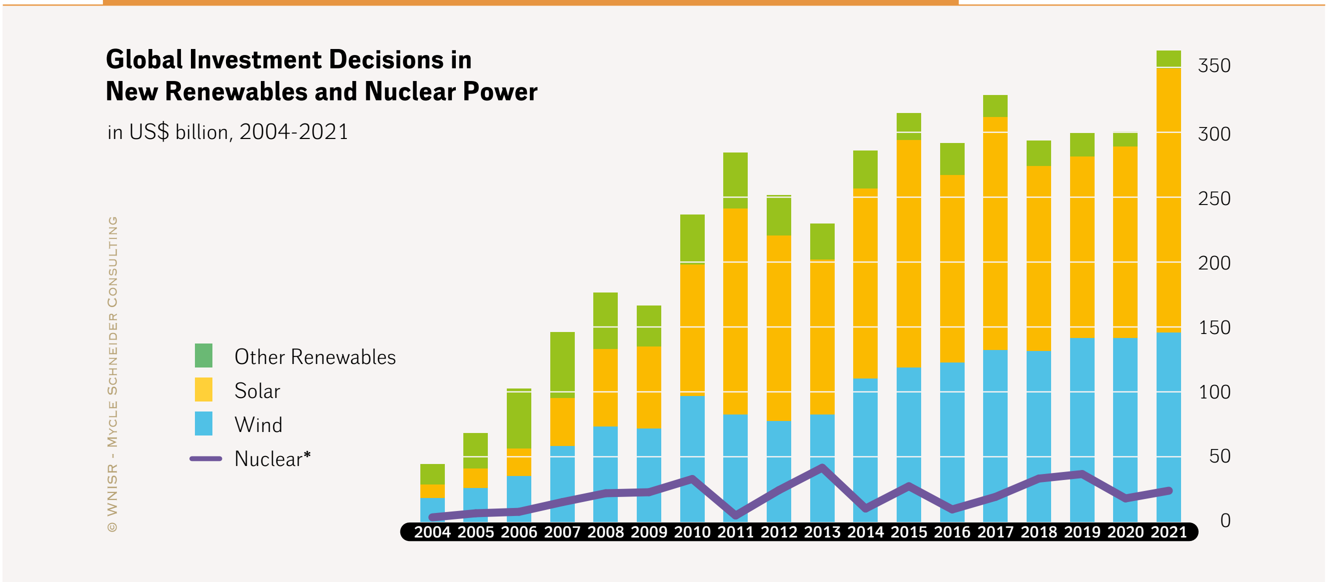
Figure 50 compares the annual investment decisions for constructing new nuclear plants with those for renewable energy since 2004. Construction began on 10 reactors in 2021, up from five in 2020, six in China, two in India and one each in Russia and Turkey. The total reported and estimated investment for the construction of the 2021-projects is around US$24 billion[1072] for 8.8 GW. During 2021, the total investment in non-hydro renewables globally, despite the economic impact of the COVID-19 pandemic, was US$366 billion, of which the individual investments in wind and solar were US$146 billion in wind power and US$204 billion in solar. This means that by the rough calculations of WNISR the nuclear investment represents about 7 percent of the renewable total. This corresponds to the assessment by Ren21 which concludes that investment in the power sector in 2021 was 69 percent renewable, 23 percent fossil fuels and 8 percent nuclear.[1073]

Globally, the relative importance of Europe and North America for renewable energy investments diminished with the rise of Asia, especially China (see Figure 51), although that relative dominance shrank in recent years. The combined investment in Europe and the U.S. in 2021 was similar to that of China and between them the three blocs make up nearly three quarters of all renewable investment in the world. Chinese nominal-dollar renewable investment rose from US$26 billion in 2008 to US$142 billion in 2017 before a steep cut, in 2018, and investment in 2021 has only just returned to this level ($137 billion).

1072 - This includes a very low reported cost for the two VVER reactors (Tianwan-7 and Xudabao-3) being built in China, which were part of a four-reactor deal reported as costing only 20 billion yuan (US$3 billion).

1073 - REN21, "Renewables 2022—Global Status Report", June 2022, p. 181, see https://www.ren21.net/reports/global-status-report/, accessed 10 July 2022.

Figure 50 · Global Investment Decisions in Renewables and Nuclear Power 2004–2021

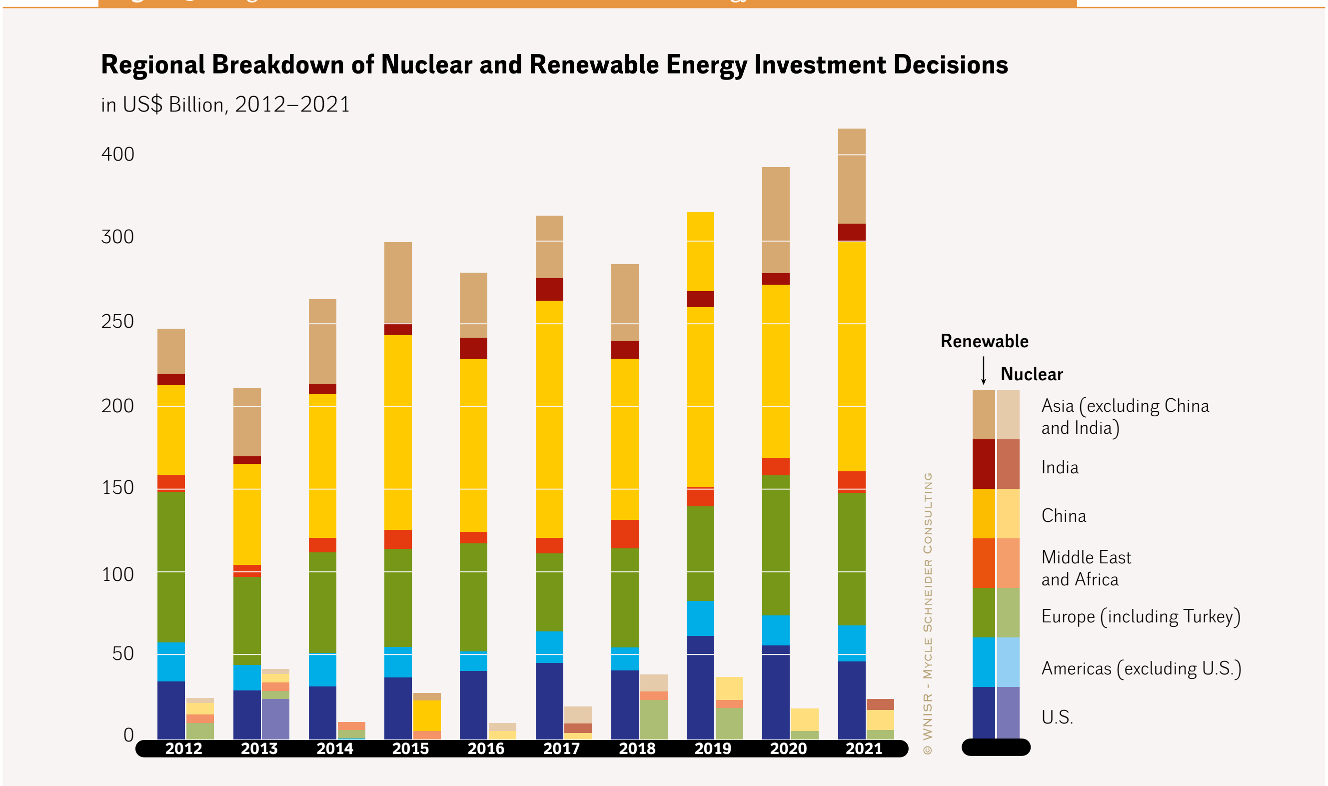


Sources: REN21 2022 and WNISR Original Research, 2022

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 in which 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.

Figure 51 · Regional Breakdown of Nuclear and Renewable Energy Investment Decisions 2012-2021

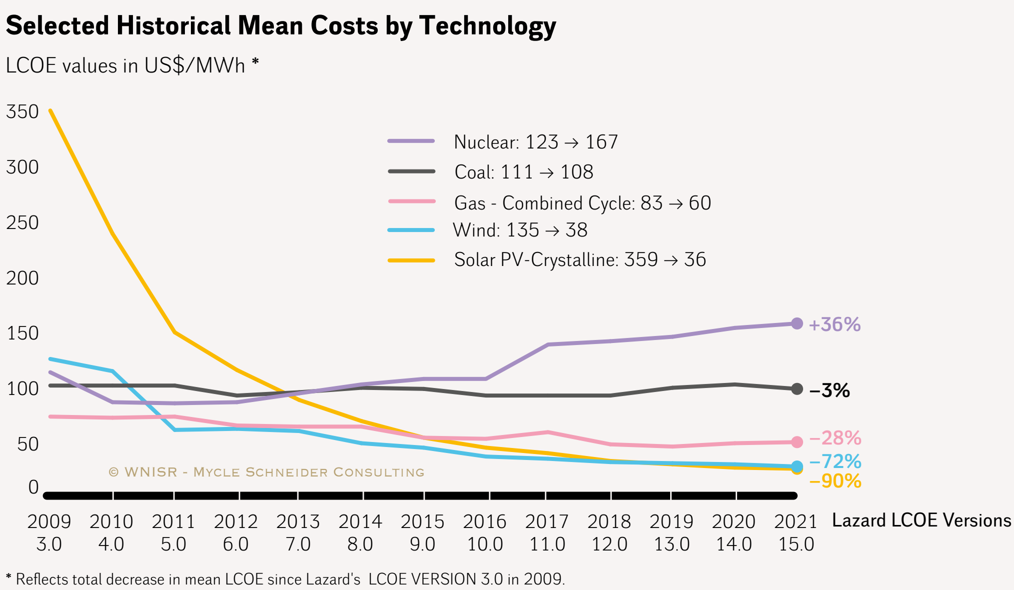


Sources: BNEF/UNEP 2022, WNISR Original Analysis, 2022

TECHNOLOGY COSTS

The annual Levelized Cost of Energy (LCOE) analysis for the U.S. last updated by Lazard, one of the oldest banks in the world, in October 2021,[1074] suggests that unsubsidized average electricity generating costs declined on average between 2009 and 2021 in the case of solar PV (crystalline, utility-scale) from US$359 to US$36 per MWh, a fall of 90 percent, and for wind from US$135 to US$38 per MWh (a 72 percent fall), while nuclear power costs went up from US$123 to US$167 per MWh, an increase of 36 percent (see Figure 52).

Figure 52 · The Declining Costs of Renewables vs. Traditional Power Sources



Source: Lazard Estimates, 2021

Notes

LCOE=Levelized Cost of Energy

*This graph reflects the average of 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 gas. According to a 2020 Bloomberg New Energy Finance (BNEF) analysis, wind and solar power are now the cheapest form of new electricity in most of the world. Furthermore, BNEF anticipated that it will be more expensive to operate existing coal or natural gas power plants within five years than to build new solar or wind farms.[1075]

In their annual review of renewable energy costs, the International Renewable Energy Agency (IRENA) concludes that in the single year 2021, the global weighted-average LCOE from

1074 - Lazard, "Lazard's Levelized Cost of Energy Analysis —Version 15.0", October 2021, see https://www.lazard.com/media/451905/lazards-levelized-cost-of-energy-version-150-vf.pdf, accessed 17 July 2022.

1075 - Jeremy Hodges, "Wind, Solar Are Cheapest Power Source In Most Places, BNEF Says", *Bloomberg*, 19 October 2020, see https://www.bloomberg.com/news/articles/2020-10-19/wind-solar-are-cheapest-power-source-in-most-places-bnef-says, accessed 6 June 2021.

new capacity additions of onshore wind declined by 15 percent to US$33/MWh compared to 2020. Over the same period, the LCOE of utility-scale photovoltaics was also down 13 percent, nearly double the rate the year before.[1076]

IRENA agrees with BNEF and calculated that 800 GW of existing coal-fired capacity in the world have higher operating costs than new utility-scale solar PV at US$57/MWh and onshore wind at US$39/MWh, including US$5/MWh for additional system integration costs. Replacing these coal-fired plants would cut annual system costs by US$32 billion per year and reduce annual emissions by around 3 billion tons of CO_2.[1077]

The same logic applies to the operation of nuclear power plants. The running of aging nuclear power plants generally leads to higher operating and maintenance costs. Only in the U.S., the nuclear industry has claimed a cost reduction of 35 percent since 2012 to US$29.4/MWh in 2020—the lowest since the collection of industry-wide data in 2002—in particular due to a 57 percent drop in capital expenditures over the period.[1078] 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 managing costs.

INSTALLED CAPACITY AND ELECTRICITY GENERATION

The continuing fall in the construction costs of renewables means that there is still an even greater rise in the net annual increase in installed capacity when investment increases. In total, a record 314 GW of renewable energy capacity (including hydro) was installed in 2021, according to REN21, an increase of 17 percent over the addition in the previous year.[1079]

The pace of wind power deployment has picked up again in 2021 with a net increase in global capacity of 92 GW, according to IRENA, leading to a global installed capacity of 823.5 GW. Importantly, significant growth has been seen in the installation of offshore wind, particularly in China and the U.S.

Solar PV deployment continues to boom, with an additional 138 GW according to IRENA (175 GW according to REN21) being installed in 2021, and increase in 25 percent, taking the global total to 848.5 GW (942 GW according to REN21).

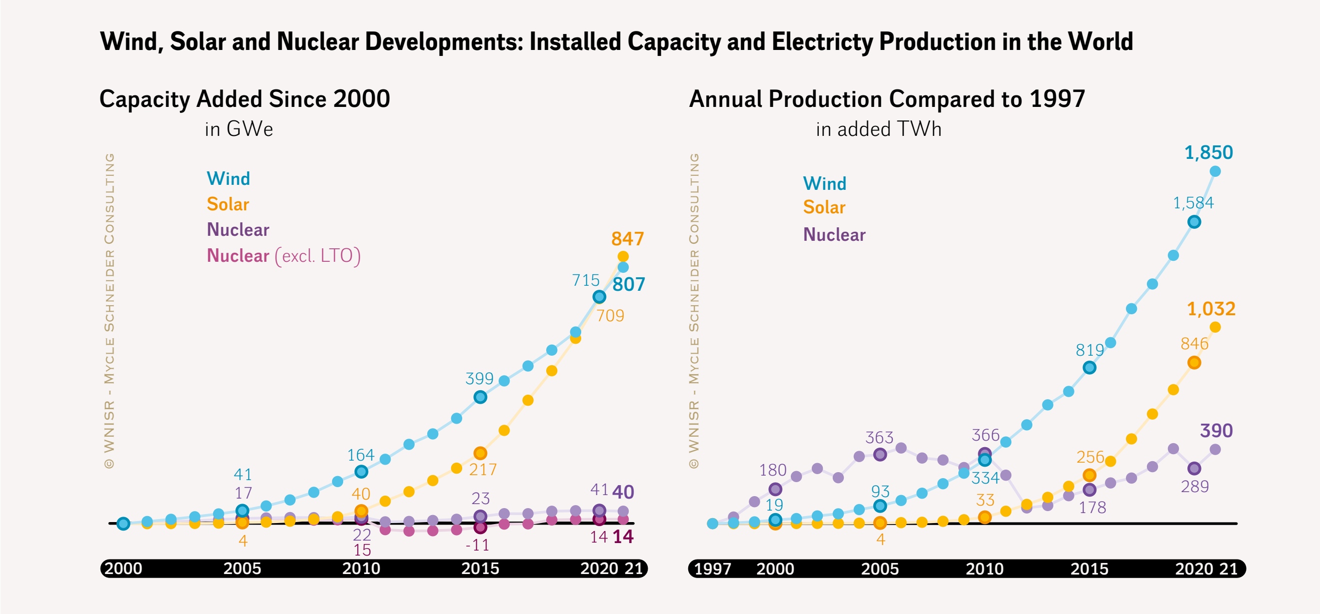
1076 - IRENA, "Renewable Power Generation Costs in 2021", International Renewable Energy Agency, July 2022, see https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021, accessed 13 July 2022.

1077 - Ibidem.

1078 - NEI, "Nuclear Costs in Context", Nuclear Energy Institute, November 2021, see https://www.nei.org/resources/reports-briefs/nuclear-costs-in-context, accessed 15 September 2022.

1079 - REN21, "Renewables 2022—Global Status Report", June 2022, op. cit.

Figure 53 · Variation of Wind, Solar and Nuclear Capacity and Electricity Production in the World



Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2022

Note pertaining to Figure 53 to Figure 56: Unless otherwise indicated, production data for nuclear are net generation, according to IAEA-PRIS; renewables gross data (and gross production for nuclear when explicitly indicated) are from BP Statistical Review. Installed capacity data are from IRENA for wind and solar and based on IAEA-PRIS for nuclear.

Figure 53 illustrates the extent to which renewables have been deployed since the start of the millennium, an increase in capacity of 807 GW for wind and of 847 GW for solar, according to IRENA, compared to the relative stagnation of nuclear power capacity, which over this period increased by around 40 GW, including all reactors currently in Long-Term Outage (LTO). Considering that 25.4 GW of nuclear power were in LTO as of the end of 2021, and thus not generating any power, the balance is an addition of just about 14 GW operating capacity compared to 2000.

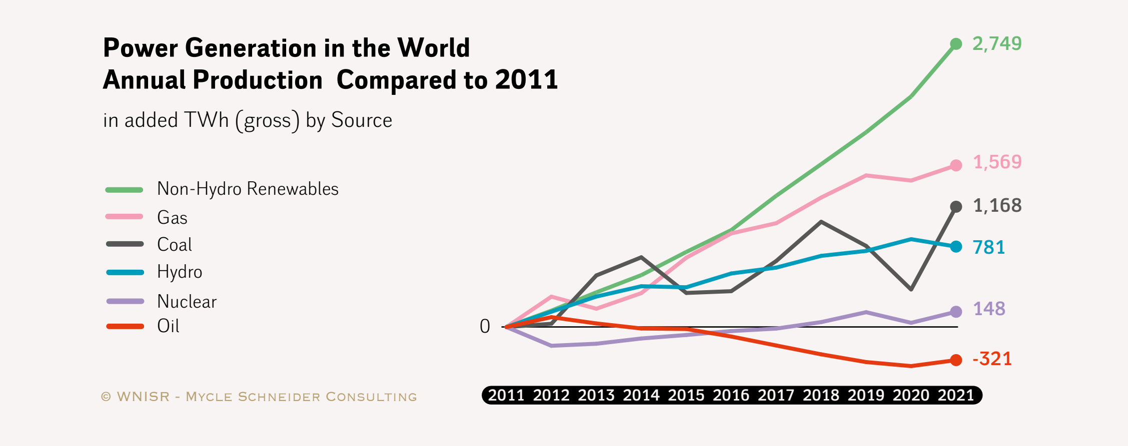
The characteristics of electricity generating technologies vary due to different load factors. In general, over the year, operating nuclear power plants produce more electricity per installed MW than renewables. However, as can be seen in Figure 53, compared to 1997, when the Kyoto Protocol was signed, there has been an additional 1,850 TWh of wind power and 1,032 TWh more solar power generated in 2021, compared to an additional 390 TWh (net)[1080] of nuclear energy. In other words, over that 23-year period, wind turbines added 4.7-times more low-carbon electricity to the world's grids than nuclear power added, while solar panels contributed 2.6 times more to the increase.

In 2021, according to BP, the annual global growth rates for the gross generation from wind power were 17.0 percent (11.9 percent in 2020), 22.3 percent (20.9 percent in 2020) for solar PV, and 4.2 percent (3.9 percent according to IAEA-PRIS) for nuclear power.

1080 - Unless otherwise indicated, production data for renewables are in gross TWh from BP, nuclear production data are usually net TWh from IAEA-PRIS, gross nuclear TWh numbers are also from BP.

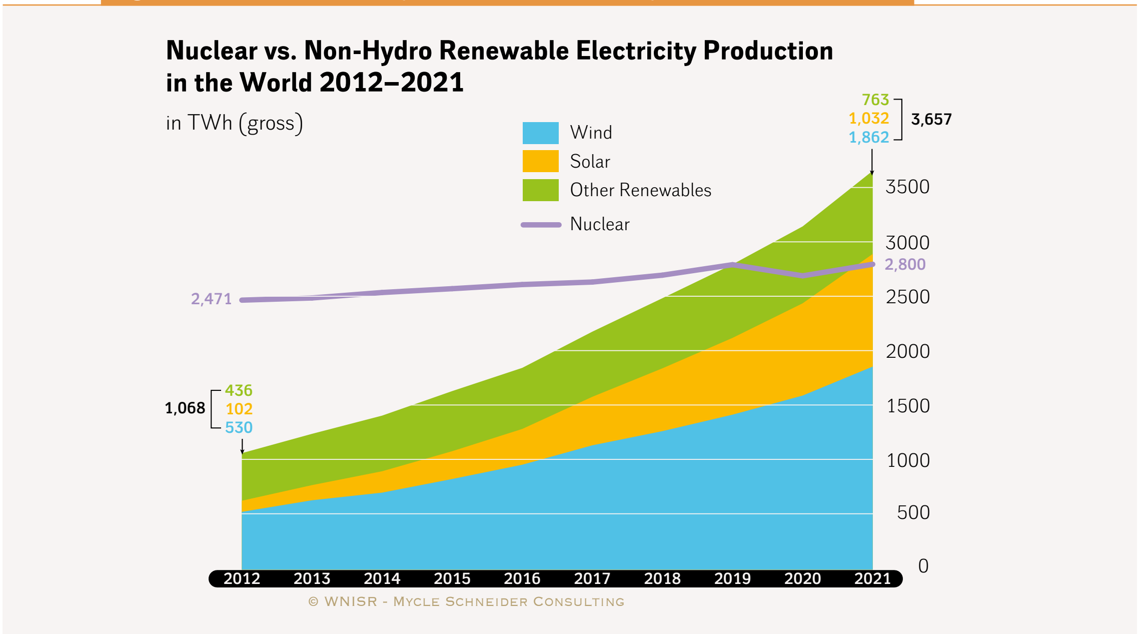
The growth of renewable energy is now not only outcompeting nuclear power but is rapidly overtaking fossil fuels and has become the source of economic choice for new generation. Figure 54 shows the extent to which, over the past decade, different energy sources have increased their electricity production. The energy source that has provided the greatest amount of additional electricity over the past decade is non-hydro renewables, generating an additional 2,749 TWh of power. The sector with the next largest growth was gas, then coal and hydro. Nuclear was the second smallest, with a net increase over the past decade of just 148 TWh, eighteen times less than the growth in non-hydro renewables.

Figure 54 · Net Added Electricity Generation by Power Source, 2011–2021



Source: BP Statistical Review, 2022

Figure 55 · Nuclear vs. Non-Hydro Renewable Electricity Production in the World



Sources: BP Statistical Review, 2022

In 2019, for the first time, non-hydro renewables—solar, wind, and mainly biomass—generated more power than nuclear plants

In 2020, with the significant drop of nuclear output, the gap widened, and renewables generated globally 16.5 percent more electricity 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 notes in its Statistical Review 2022.

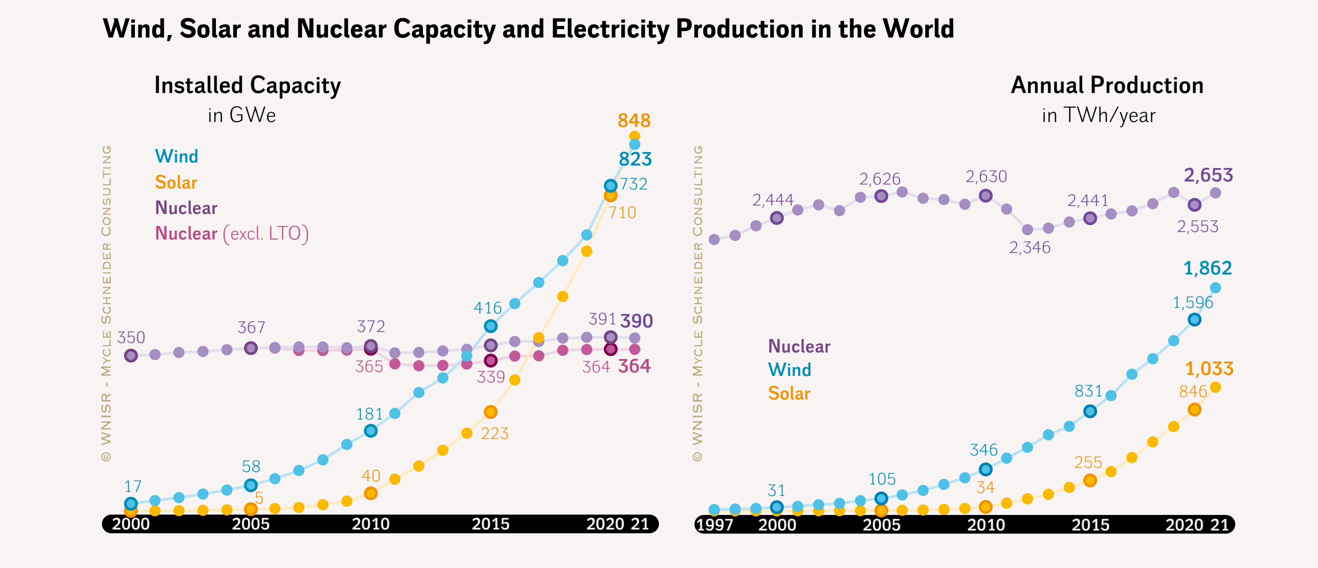
"The individual installed capacity of both solar and wind is exceeding double that of nuclear power."

While nuclear generation slightly recovered in 2021, it remained below the 2019 level and the gap has almost doubled in size: non-hydro renewables generated 30.6 percent more power than nuclear plants and, for the first time, the combined output of solar and wind alone is exceeding that of nuclear power. It took these industries just 20 years to achieve what the nuclear industry took more than half a century to accomplish (see Figure 55).

As Figure 56 shows, for the first time:

- the installed solar capacity exceeds that of wind;
- the individual installed capacity of both solar and wind is exceeding double that of nuclear power.

Figure 56 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in the World



Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2022

Note: see Figure 53.

STATUS AND TRENDS IN CHINA, THE EUROPEAN UNION, INDIA, AND THE UNITED STATES

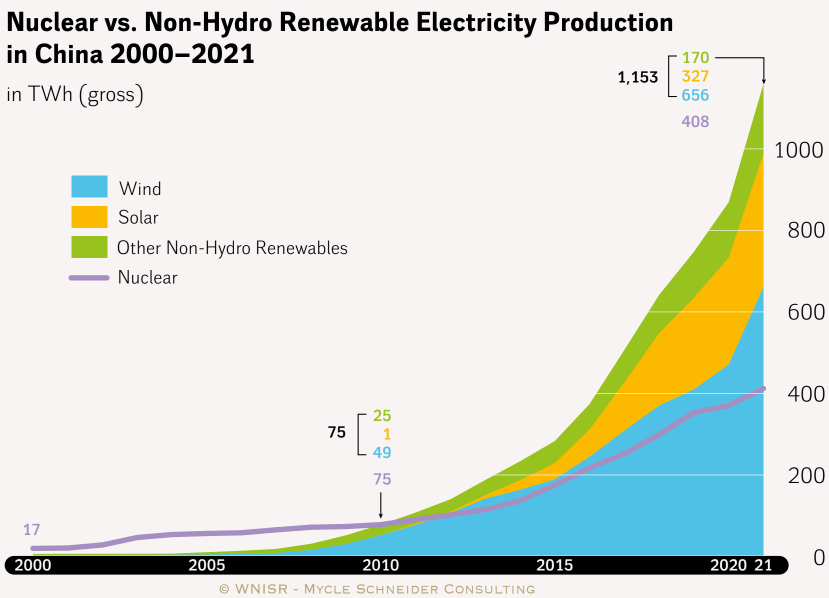
China

China remains one of the most important countries in terms of renewable energy manufacturing and deployment, and the latest Ernst & Young Renewable Energy Country Attractiveness index has once again China in second spot behind the U.S.[1081] China was the global leader prior to October 2019.

In 2021, electricity consumption in China increased by 10.4 percent, compared to an average increase of 7.1 percent in the previous two years.[1082] In the case of China, there is usually a range of numbers for capacity and production volumes of energy, depending on the references, especially for renewable sources.

In 2021, renewable-energy-based gross power generation grew faster than any other energy sources, with wind producing 656 TWh, solar, 327 TWh, compared to 407.5 TWh (383 TWh net) for nuclear and 1,300 TWh for hydro, according to data from BP (see Figure 58). Thus, wind turbines generated 71 percent more power than nuclear reactors and solar remained just 15 percent short of the nuclear output.

Figure 57 · Nuclear vs Non-Hydro Renewables in China, 2000–2021



Source: BP Statistical Review, 2022

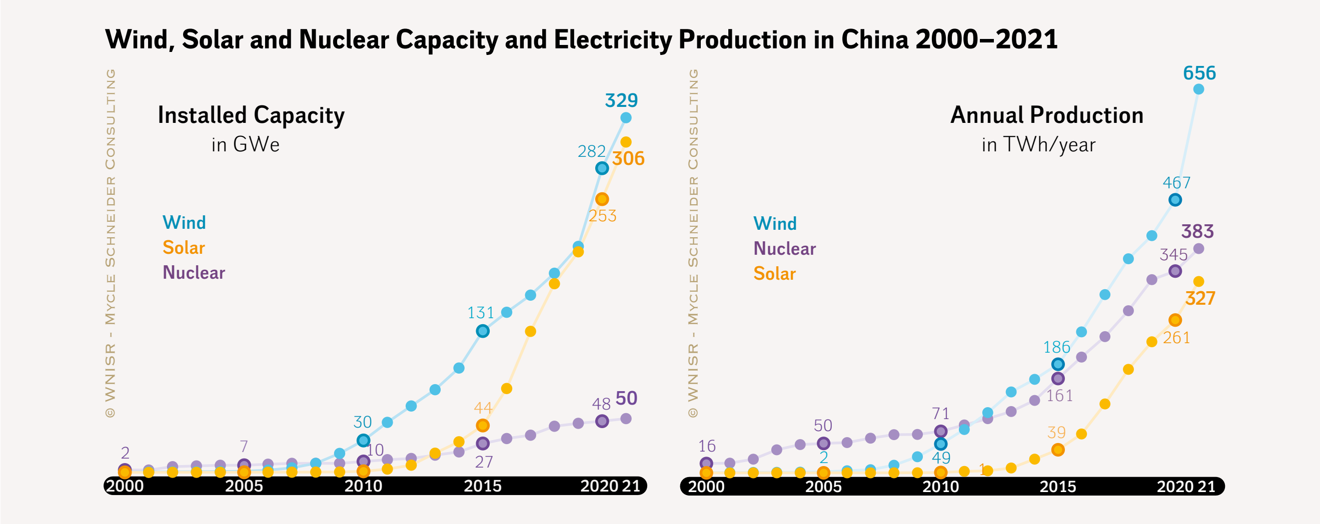
1081 - EY, "Renewable Energy Country Attractiveness Index (RECAI)—59th Edition", May 2022, see https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/power-and-utilities/ey-recai-59-edition-full-report-may-2022.pdf, accessed 25 August 2022.

1082 - CEC, "Data of Electricity Consumption (Jan to Dec 2021)", China Electricity Council, 30 January 2021; and CEC, "CEC Released the Annual Report on Development of China's Power Industry 2022", 11 July 2022, see http://english.cec.org.cn/#/newsdetails?id=1550040674299142145, accessed 26 August 2022.

Especially the solar developments are accelerating in a breathtaking manner. After having added a record 53 GW in 2021, the first half of 2022 saw 31 GW connected to the grid, an increase of 137 percent over the first half of 2021.[1083]

Nuclear output grew by an impressive 5.4 times between 2010 and 2021, while wind increased 13 times and solar over 450 times. As can be seen in Figure 57 based on data published by BP (which differ slightly from that published by Chinese organizations) the total amount of energy generated by non-hydro renewables in 2021 is more than double that by nuclear power. This growth is all the more remarkable as these technologies only surpassed nuclear power a decade ago, and China is by far the world's leading developer of nuclear power.

Figure 58 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in China, 2000–2021



Sources: WNISR with IRENA, BP, IAEA-PRIS, 2022

China's energy and climate policies are determined primarily by five-year plans and the National Energy Strategy (2016–2030), set initially on the national level and then translated into provincial- and city-level targets. In March 2021, the Central Government announced its intentions for the 14th Five Year Plan (2021–2025), suggesting that the share of non-fossil fuels in the energy mix increase to 20 percent, up from 15 percent in the current 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.

In January 2022, the government published the paper "14th Five Year Plan for a Modern Energy System" which gives more details of the plans for the power sector through to 2025. The report, even though it was published before the start of the Russian invasion of Ukraine, refocuses the energy sector towards security. Gone is a specific consumption target and in is a target on production capacity. For the first time the plans set a target for the non-fossil generation, rather than specific targets for renewables or wind power. The plan is that by 2025,

1083 - David Stanway, "China solar installations more than double in first half - assn", *Reuters*, 21 July 2022, see https://www.reuters.com/business/energy/china-solar-installations-more-than-double-first-half-assn-2022-07-21/, accessed 25 July 2022.

39 percent of power should be generated by non-fossil sources.[1084] According to BP, non-fossil sources in 2021 provided 33.5 percent of power of which 15.2 percent from hydro, 13.5 percent from non-hydro renewables and 4.8 percent from nuclear power.

China's initial NDC submission to the UNFCCC in 2015 indicated that it would aim to peak CO_2 emissions around 2030 and make best efforts to peak early. In September 2020, to the surprise of many, President Xi said China would aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality by 2060. The new target is in line with previous announcements. At the U.N. Climate Ambition Summit in December 2020, President Xi announced that China would lower its CO_2 emissions per unit of GDP by 65 percent from 2005 levels and increase the share of non-fossil fuels in primary energy consumption to around 25 percent by 2030—a welcome announcement since in 2021, according to BP data, coal accounted for more than half (54.7 percent) of the country's total primary energy consumption, while oil represented 19.4 percent and natural gas 8.6 percent, which compares to hydroelectricity with 7.8 percent, non-hydro renewables 7.2 percent and nuclear 2.3 percent. This target is for energy as a whole, and it is suggested that by 2030 at least 40 percent of electricity will come from non-fossils[1085] In order to achieve this goal, President Xi pledged an additional combined 1,200 GW of solar and wind capacity by 2030, which, while representing a vast increase from current installed capacity levels, is along current trajectories, rather than a step-change in the rate of growth.[1086]

The targets for nuclear are less clear, but some government researchers suggest it could be about 130 GW by 2030, a more than doubling of current capacity.[1087] However, such targets are unlikely, given the long construction times of nuclear—in most countries at least five years, ten years on global average, and even in China an average of six years over the past decade—with only 19.5 GW under construction as of end of 2021, of which around 11 GW expected to come online by the end of 2025. Therefore, at best, China will have a total of 61 GW of nuclear capacity operating by the end of the 14th Five Year Plan. The total capacity operating and under construction as of 1 July 2022 represents around 72 GW. Therefore 100 GW of operating nuclear capacity by 2030 seems more realistic, which would still make it the world's largest reactor fleet, but an order of magnitude below the installed capacity and significantly below the output of each, solar and wind, individually.

1084 - *China Dialogue*, "New five-year plan for energy: long on system building, short on decarbonisation", 24 March 2022, see https://chinadialogue.net/en/digest/new-five-year-plan-for-energy-long-on-system-building-short-on-decarbonisation/, accessed 10 July 2022.

1085 - Muyu Xu and David Stanway, "China plans to raise minimum renewable power purchase to 40% by 2030: government document", *Reuters*, 10 February 2021, see https://www.reuters.com/article/us-china-climatechange-renewables-idUSKBN2AA0BA, accessed 2 June 2021.

1086 - Lin Jiang and He Gang, "China can benefit from a more ambitious 2030 solar and wind target", *China Dialogue*, 2 February 2021, see https://chinadialogue.net/en/energy/china-can-benefit-from-a-more-ambitious-2030-solar-and-wind-target/, accessed 2 June 2021.

1087 - Jason Rogers and Feifei Shen, "China to miss nuclear energy target this year, but has eyes set on dominating sector by 2030", *The Print*, 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 2 June 2021.

European Union

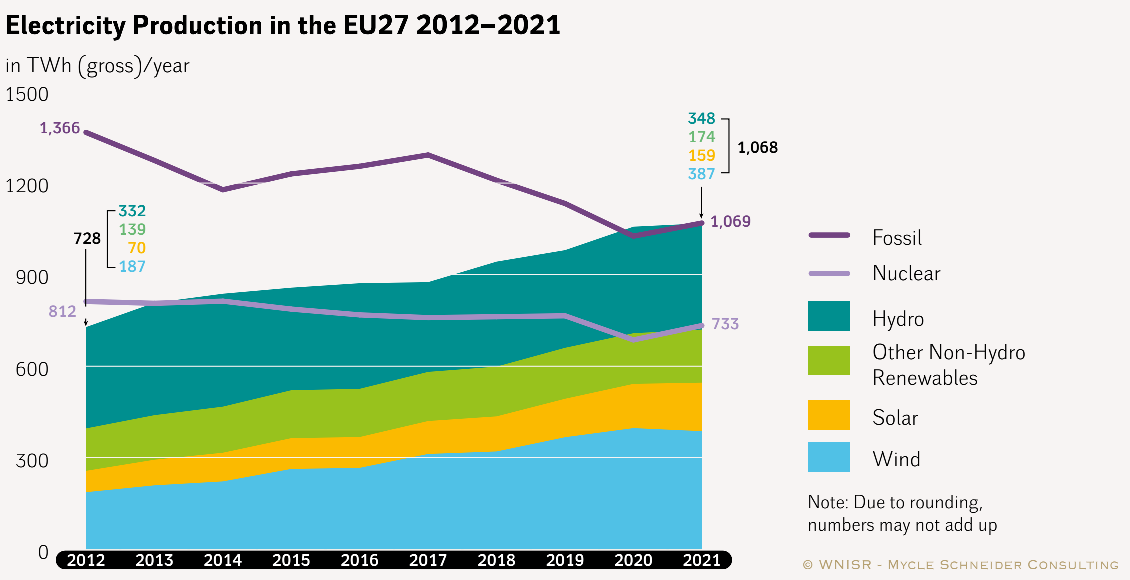
Between 2019 and 2020, electricity demand in the E.U. fell 3.5 percent (-100 TWh) but recovered nearly all of the decline in 2021, rising 3.4 percent (+95 TWh) year-on-year, although underlying weather-related factors indicate that a full return to pre-COVID levels has not occurred.

In 2021, renewable electricity generation in the E.U. reached a new record of 1,068 TWh, a 1 percent increase (+12 TWh) year-on-year—a 9 percent (+88 TWh) jump compared to 2019—and accounted for 37 percent of the E.U.'s electricity production in 2021, up from 34 percent in 2019.[1088] (See Figure 59).

In comparison nuclear power produced 733 TWh gross (699 TWh net)—around 7 percent more than the previous year—but about 4 percent lower (-32 TWh) than in 2019, primarily caused by reactor closures and the mediocre performance of the French nuclear fleet. Nuclear accounted for 26 percent of E.U. electricity production in 2021, down from 29 percent ten years ago.[1089]

In 2021, natural gas still accounted for 19 percent of the total electricity generation, coal 15 percent, and oil 1.5 percent. Based on BP-data, their respective share in primary energy consumption represented 11.2 percent for coal, 23.8 percent for natural gas and 35.5 percent for oil.

Figure 59 · Electricity Generation in the EU27 by Fuel, 2012–2021



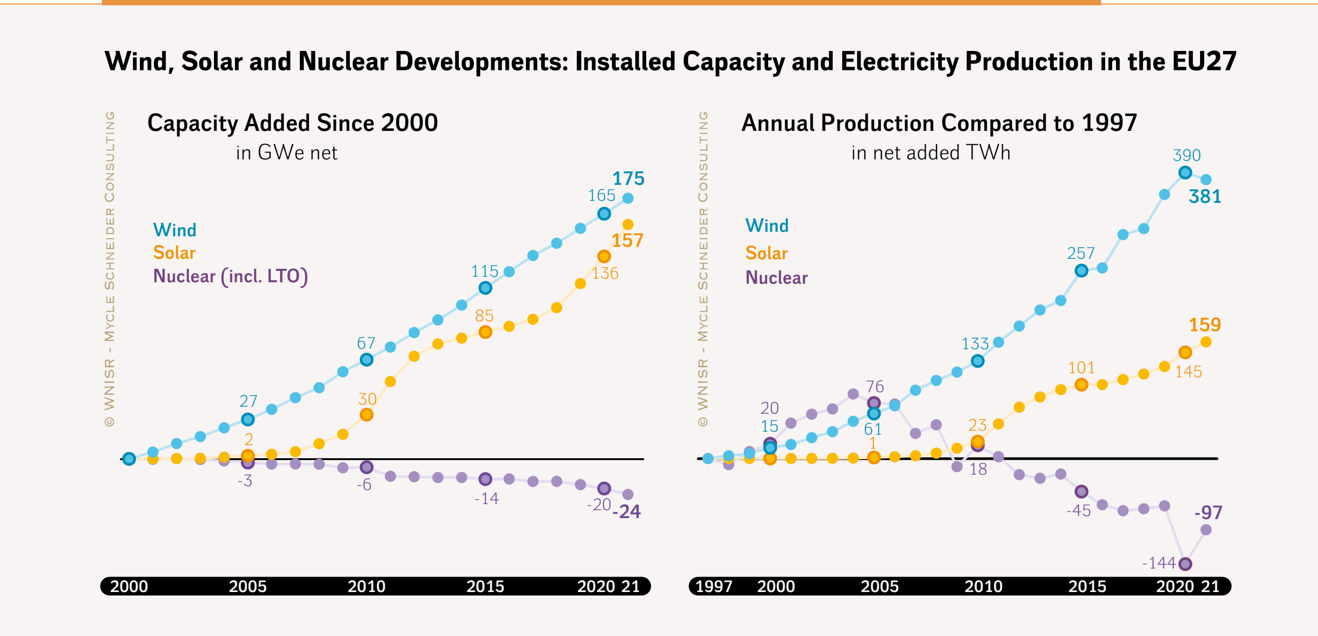
Sources: IAEA-PRIS, Agora Energiewende and Ember, 2022

Since 2000, wind added 175 GW of installed capacity, solar 157 GW, while nuclear declined by 24 GW. Since the signature of the Kyoto Protocol in 1997, wind and solar increased annual production by 380.5 TWh and 159 TWh respectively, while nuclear generated 97 TWh less power (-106 TWh gross) (see Figure 60 and Figure 61).

1088 - Ember, "European Electricity Review 2022", 1 February 2022, see https://ember-climate.org/insights/research/european-electricity-review-2022/, accessed 18 June 2022.

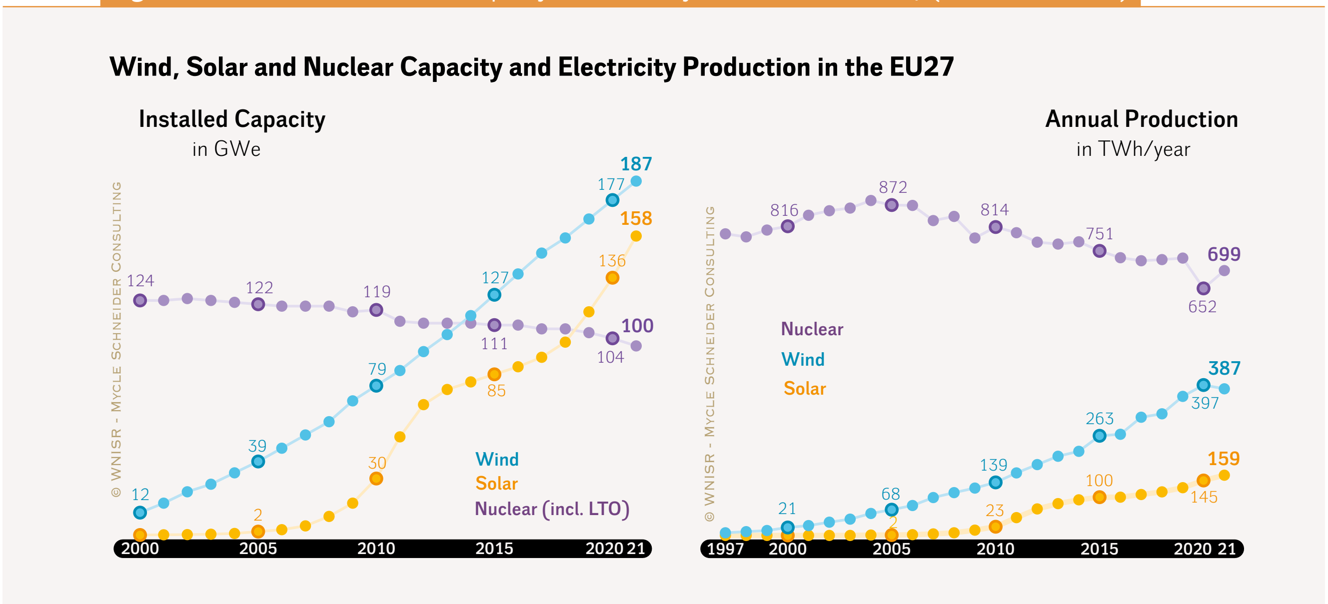
1089 - Ibidem.

Figure 60 · Wind, Solar and Nuclear Capacity and Electricity Production in the EU27 (Developments)



Sources: WNISR with IAEA-PRIS, IRENA, EMBER, Eurostat, 2022

Figure 61 · Wind, Solar and Nuclear Capacity and Electricity Production in the EU27 (Absolute Numbers)



Sources: WNISR with IAEA-PRIS, IRENA, EMBER, Eurostat, 2022

In September 2020, the European Commission proposed to increase the E.U.'s greenhouse gases (GHG) reduction-target to at least 55 percent by 2030 from 1990 levels, up from the 40-percent minimum target set prior to the signing of the Paris Agreement in 2015. This increase was then approved by the E.U. Heads of State in December 2020, and formally submitted as a revised NDC to the UNFCCC. 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% to 39%."[1090] This is total final energy and would mean renewables providing up to 80 percent of power, requiring a significant acceleration of the current rate of renewable electricity deployment. There is no E.U.-wide nuclear deployment target.

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 REPowerEU plan. This introduced a number of supply and demand side measures to simultaneously reduce dependency on Russia and address climate change. A cornerstone to the new plan was, as the name suggests, and increase in renewable energy, with an ambition that they should provide 45 percent (up from 40 percent) of the E.U.'s final energy by 2030, more than double its current contribution.[1091]

This included a specific solar strategy to more than double 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 on new public and commercial buildings and the residential sector, as well as changes in planning and new targets on the production of hydrogen from renewable sources. In contrast, on nuclear power the 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, no targets, no additional support, and only a brief reference to its existing role and a desire to reduce dependency on uranium imports from Russia.[1092]

If the new European energy policy is fully implemented the E.U. will have a power sector that is fundamentally dominated by renewable energy.

India

Since 2010, the installed capacity of solar in India has increased by a factor of over 700 from 70 MW to 49.7 GW at the end of 2021 overtaking for the first time, the installed capacity of wind—that increased by a factor of three over the same period from 13.8 GW to 40.1 GW—while nuclear capacity has grown from about 4 GW to 6.8 GW (including 3 reactors / 0.5 GW in Long-Term Outage). In its NDC submitted in 2016, India estimates that by 2030, electricity demand will more than triple its 2012-level, growing from 776 TWh in 2012 to 2,499 TWh in 2030.[1093]

Figure 62 shows that since the turn of the century, wind power output has grown rapidly, from 1.45 TWh to 68.1 TWh in 2021 and has overtaken nuclear's contribution to electricity

1090 - European Commission, "2030 Climate Target Plan", 11 September 2020, see https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en; and European Commission, "Commission Staff Working Document—Impact Assessment", Accompanying "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—Stepping up Europe's 2030 climate ambition—Investing in a climate-neutral future for the benefit of our people", 17 September 2020, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020SC0176, both accessed 25 August 2022.

1091 - European Commission, "REPowerEU Plan", 18 May 2022, see https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX%3A52022DC0230, accessed 18 June 2022.

1092 - Ibidem.

1093 - Government of India, "India's Intended Nationally Determined Contribution: Working Towards Climate Justice", submitted 2 October 2016, see https://unfccc.int/sites/default/files/NDC/2022-06/INDIA%20INDC%20TO%20UNFCCC.pdf, accessed 25 August 2022.

generation since 2016, which now stands at 39.6 TWh. Solar is growing even faster, from a production of 7 GWh in 2000 to 68.3 TWh in 2021—that represents 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. In 2021, according to BP-data, fossil fuels still accounted for about 78 percent of the country's electricity generation, with coal contributing 74.1 percent, natural gas 3.74 percent and oil about 0.1 percent.

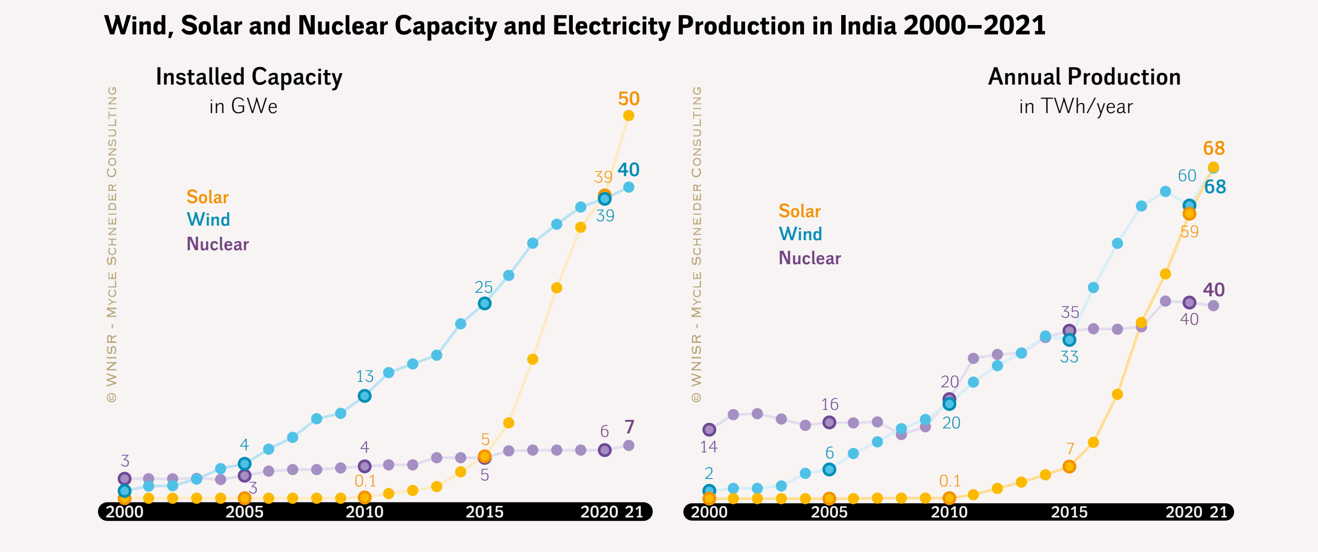
The gap in output between renewables and nuclear will likely increase in the coming years, because of the rapid growth of solar and wind capacity, and stagnation in the nuclear sector. Nuclear generation has actually slightly declined over the past two years (see Figure 62).

In 2016, India has put in place ambitious targets for the deployment of renewables with 175 GW by the end of 2022—including 100 GW solar and 60 GW wind—and 450 GW by 2030. As noted, at the end of 2021, solar and wind between them had less than 100 GW of installed capacity and reaching the 2022 target is clearly not possible.

The failure to meet targets occurs despite world-beating falling costs. IRENA reported that, between 2010 and 2021, the global weighted average total installed cost of onshore wind capacity fell by 35 percent, from US$2,042/kW US$1,325/kW, with India having some of the greatest falls in costs during the period from US$1,415/kW to internationally the lowest cost in 2021 of US$926/kW.[1094]

Due to India's struggle to meet its targets, the country dropped from third to seventh place in Ernst & Young's latest Renewable Energy Country Attractiveness Index.[1095]

Figure 62 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in India



Sources: WNISR with IAEA-PRIS, IRENA, BP, 2022

1094 - IRENA, "Renewable Power Generation Costs in 2021", July 2022, op. cit.

1095 - EY, "Renewable Energy Country Attractiveness Index (RECAI)—59th Edition", May 2022, op. cit.

United States

As of mid-2022, the U.S. had 92 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 (852 TWh gross) supplying just under 20 percent of the nation's electricity, but by 2021 had fallen to 772 TWh, the lowest generation level since 2012. The decline was only partially due to a reactor closure in April 2021 (Indian Point-3). Apparently, overall performance that had been exceptionally high over the entire past decade has been degrading.

In contrast, the U.S. generated a record amount of renewable energy in 2021, about 14 percent of the total, the seventh year of continual growth. In 2019, wind turbines overtook nuclear in capacity and outpaced hydro in production. In 2021, wind power generation increased by a further 13 percent while the generation of solar increased by 25 percent, according to BP (see Figure 63).

"Nuclear energy consumption dropped to the lowest level since 2012."

In terms of primary energy, consumption of renewables increased by 7 percent to a new record in 2021. Increased use of renewables for electricity generation, including wind and solar energy, was partially offset by a decline in hydroelectricity generation. While nuclear energy consumption dropped to the lowest level since 2012. In terms of share to the total primary energy consumption, combined non-fossil fuel energy sources contributed 21 percent, with fossil fuel representing the remaining 79 percent in 2021. That year coal consumption increased for the first time since 2013.[1096]

The growth in renewables is expected to increase as more capacity comes online. In 2019, 2020, and 2021 more wind was installed than any other power source, with 17 GW in 2021, a new annual record. Solar deployment continues to accelerate and in 2021, 15.5 GW were deployed. The EIA estimated that almost half of the planned 2022 capacity additions are solar (21.5 GW) followed by natural gas at 21 percent (9.6 GW) and wind at 17 percent (7.6 GW), while nuclear represents a 5 percent share with 2.2 GW.[1097] Solar capacity will have overtaken installed nuclear capacity in 2022.

The election of President Biden in 2020 led to a significant change in direction on several issues, but particularly on climate change, including the rejoining of 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.[1098] Part of this carbon-reduction plan is in the power sector, with a pledge to put the U.S. "on the path to achieving 100 percent carbon-free electricity by 2035".[1099]

1096 - *Today in Energy*, "Fossil fuel sources accounted for 79% of U.S. consumption of primary energy in 2021", U.S. Energy Information Administration, 1 July 2022, see https://www.eia.gov/todayinenergy/detail.php?id=52959, accessed 10 July 2022.

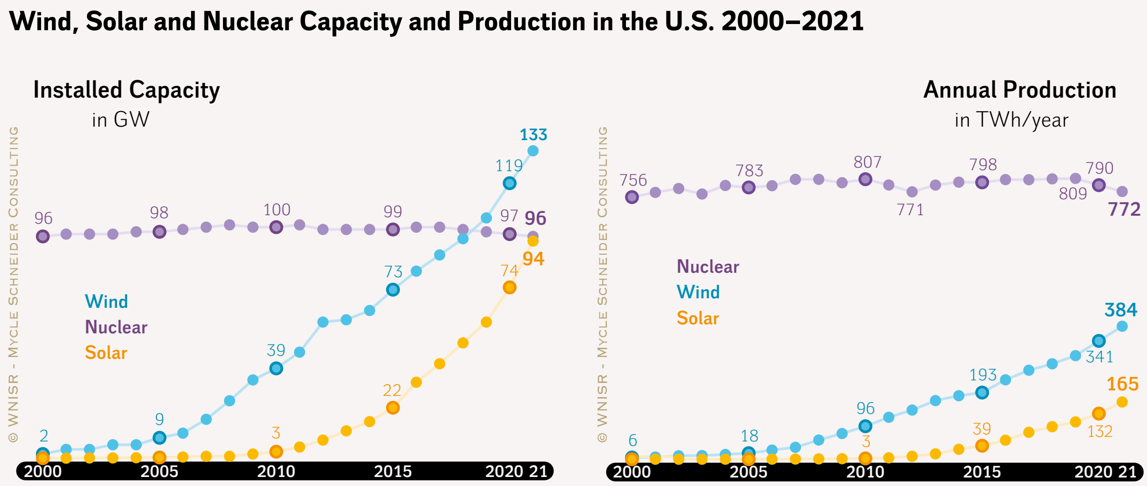
1097 - Elesia Fasching and Suparna Ray, "Solar power will account for nearly half of new U.S. electric generating capacity in 2022", *Today in Energy*, U.S.EIA, 10 January 2022, see https://www.eia.gov/todayinenergy/detail.php?id=50818, accessed 10 July 2022.

1098 - U.S. Department of State, "", Leaders Summit on Climate: Day 1", 22 April 2021, see https://www.state.gov/leaders-summit-on-climate/day-1/, accessed 26 August 2022.

1099 - The White House, "FACT SHEET: The American Jobs Plan", U.S. Government, Press Release, 31 March 2021, see https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/, accessed 8 July 2021.

As documented earlier in the chapter, the costs of renewables in the U.S., see Figure 52, are considerably below that of nuclear energy. Furthermore, the U.S. remains the number one country globally for renewable energy investment, according to the latest Ernst & Young Renewable Energy Country Attractiveness index,[1100] and hosts some of the lowest renewable energy generating costs.[1101]

Figure 63 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in the U.S



Sources: BP, IRENA, IAEA-PRIS, WNISR, 2022

CONCLUSION ON NUCLEAR POWER VS. RENEWABLE ENERGY

2022 will be a key year for the energy transition and its impact on energy security and climate change. 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 the science. Climate change in many parts of the world was a priority during 2021, in particular 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. Russia's invasion of Ukraine has however 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, as Russia is a major exporter of energy, and we are almost certain to see further price rises and the subsequent cost of living crisis across the world. Therefore, measures need to be put in place that can rapidly and as cheaply as possible remove the need for fossil fuels, especially from Russia. Clearly, a top priority must be energy efficiency and conservation, which is the best measure for addressing the energy trilemma simultaneously and with focused public information campaigns can happen quickly.

1100 - EY, "Renewable Energy Country Attractiveness Index (RECAI)—59th Edition", May 2022, op. cit.

1101 - IRENA, "Renewable Power Generation Costs in 2021", July 2022, op. cit.

"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"

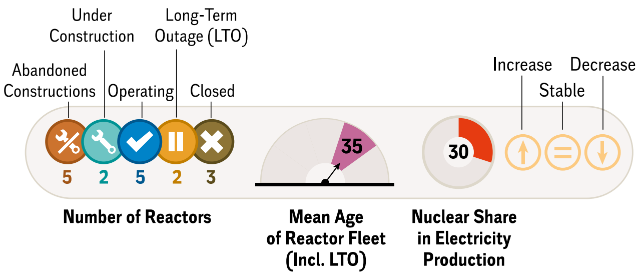
On the supply side, 2021 and 2022 have once again shown that renewable energies outperform nuclear power in terms of cost, and as is shown throughout this report, nuclear power is slow to implement. Therefore, although, there has been increased attention to nuclear power recently, it is the deployment of renewable energy, as graphically demonstrated in the E.U., that is being promoted as the supply solution. As Antonio Gueterres, the Secretary General of the United Nations 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".[1102]

1102 - António Guterres, "We are still addicted to fossil fuels", Twitter, 9 July 2022, see https://twitter.com/antonioguterres/status/1545725702472966145, accessed 10 July 2022.

TABLE OF ANNEXES

ANNEX 1 – OVERVIEW BY REGION AND COUNTRY

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

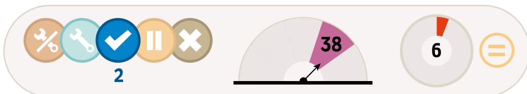


Unless otherwise noted, data on reactor capacity (as of mid-2022) and nuclear's share in electricity generation in 2021 are from the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS) online database.

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



South Africa hosts the only commercial nuclear power plant on the continent consisting of two 900 MW reactors located at Koeberg, near Cape Town. Both reactors started operating in the mid-1980s. In 2021, they generated 12.2 TWh representing 6 percent of the country's power, down from the historical maximum of 7.4 percent in 1989. 2020 was a landmark year for the South African grid, as variable renewables—namely solar and wind—produced more electricity than the nuclear power plant for the first time.[1103] In 2021, renewable energy produced 16.8 TWh or 7.4 percent of total electricity in South Africa.

The reactors were initially permitted to operate for 40 years and are now subject to a series of replacement and upgrading work to extend their operational lifetimes by 20 years to 2045.[1104] In May 2021, Eskom submitted an application for a lifetime extension of the plant,[1105] and as of May 2022, Eskom planned to submit the "required supporting documentation" to the regulator

1103 - Remeredzai Joseph Kuhudzai, "Solar & Wind In South Africa Contributed More Than Nuclear For 1st Time Ever In 2020", *CleanTechnica*, 13 March 2021, see https://cleantechnica.com/2021/03/13/solar-wind-in-south-africa-contributed-more-than-nuclear-for-1st-time-ever-in-2020/, accessed 26 June 2021.

1104 - Kevin Brandt, "Koeberg nuclear plant components can run beyond 2045, say experts", *Eyewitness News*, 5 November 2019, see https://ewn.co.za/2019/11/05/koeberg-nuclear-plant-components-can-run-beyond-2045-say-experts, accessed 25 June 2021.

1105 - Eskom, "Application To Operate the Koeberg Nuclear Power Stations (KNPS) Beyond the Timeframe Established in the Nuclear Installation Licence No. NIL-01 (Variation 19)", filed with NNR, National Nuclear Regulator, 10 May 2021, see https://nnr.co.za/wp-content/uploads/2022/02/K-27660-E-10May2021-Application-to-Operate-the-Koeberg-Nuclear-PS-Beyond-the-Timeframe-Established-in-the-Nuclear-Installation-Licence-No.-NIL-01.pdf, accessed 9 September 2022.

for evaluation by June 2022.[1106] At the end of July 2022, "the National Nuclear Regulator (NNR) confirmed that Eskom submitted the safety case in support of its application to extend the operational life of the Koeberg Nuclear Power Station beyond the current licence term", thus starting a "process of robust scrutiny" from NNR.[1107]

The Steam Generator Saga

The decision to replace all six steam generators of the two reactors was taken in 2010, the NNR was informed in 2011,[1108] AREVA was awarded the contract in 2014[1109], and a lengthy legal battle with competitor Westinghouse followed, one that Westinghouse eventually lost. Both Eskom and Areva had stated that they considered it critical for the safe operation of the plant, and for the security of electricity supply in South Africa, that the steam generators should be finally replaced during the scheduled outage in 2018.[1110] That did not happen. By mid-2021, Eskom was frequently practicing load-shedding (power rationing) to cope with the lack of generating capacity.

In 2018, the Parliament began investigations into the actions of several Eskom officials relating to possible corruption, including the steam generator contracts. The Parliament committee report concluded that the former chairmen and executives of Eskom "reasonably ought to have known or suspected" that their failure to report the flouting of governance rules relating to some contracts, including those relating to the steam generator replacement "may constitute criminal conduct".[1111]

Contractually, the six steam generators should have been delivered by February 2018 and installed by the end of 2019, but a series of serious manufacturing problems delayed the process. Following the discovery of systematic irregularities in 2016 (see France Focus in earlier WNISR editions), forging of large pieces had been interrupted at Framatome's Creusot Forge until late 2020. The Koeberg steam generators were only partially manufactured. They were sent to Framatome's Chinese subcontractor Shanghai Electric Nuclear Power Equipment Company (SENPEC) who decided to scrap the incomplete steam generators as they were found failing technical specifications and started all over.[1112]

1106 - Eskom, "Eskom pins hopes on returning Koeberg and Kusile power station units to reduce pressure on constrained power system", Press Release, 11 May 2022, see https://www.eskom.co.za/eskom-pins-hopes-on-returning-koeberg-and-kusile-power-station-units-to-reduce-pressure-on-constrained-power-system/, accessed 18 May 2022.

1107 - NNR, "NNR receives safety case in support of the application to extend the operational life of the Koeberg Nuclear Power Station beyond the current licence term of 40 years.", National Nuclear Regulator, 28 July 2022, see https://nnr.co.za/wp-content/uploads/2022/07/NNR-MEDIA-RELEASE-27July-22-NNR-Receives-Koeberg-LTO-Safety-Case-1.pdf, accessed 13 August 2022.

1108 - NNR, "National Nuclear Regulator (NNR) Update on the Regulatory Oversight of the Koeberg Nuclear Power Station", Press Release, 3 February 2022, see https://nnr.co.za/wp-content/uploads/2022/02/NNR-Media-Release-030222-Nuclear-Safety-Regulatory-Update-on-Koeberg-Oversight.pdf, accessed 5 June 2022.

1109 - *NEI Magazine*, "AREVA to replace steam generators at Koeberg", 19 August 2014, see https://www.neimagazine.com/news/newsareva-to-replace-steam-generators-at-koeberg-4346550/, accessed 25 June 2021.

1110 - Chris Yelland, "Steam generators for Koeberg: 'the most expensive transport of scrap metal in the history of humankind'", *Daily Maverick*, 5 October 2020, see https://www.dailymaverick.co.za/article/2020-10-05-steam-generators-for-koeberg-the-most-expensive-transport-of-scrap-metal-in-the-history-of-humankind/, accessed 5 June 2022.

1111 - Renee Bonorchis and Ana Monteiro, "Three former Eskom chairmen to be criminally probed", *Bloomberg*, as published on *BizNews.com*, 28 November 2018, see https://www.biznews.com/briefs/2018/11/28/eskom-chairmen-criminal-probe, accessed 25 June 2021.

1112 - Chris Yelland, "Steam generators for Koeberg: 'the most expensive transport of scrap metal in the history of humankind'", *Daily Maverick*, 5 October 2020, op. cit.

Finally, the first three steam generators built by SENPEC arrived at the Koeberg site in September 2020.[1113] By then, the replacement of the steam generators at Unit 1 was scheduled to be carried out in 2021,[1114] and on Unit 2, installation was planned to start in January 2022. But supply difficulties caused by the COVID-19 pandemic, "setbacks with the submission of the installation safety case and associated safety and operational documentation to the NNR" as well as "delay with the construction of the original Steam Generator Interim Storage Facility [a facility designed for the temporary storage of the original steam generators at the Koeberg site]" caused the refurbishment of Unit 1 to be delayed to its next planned outage in September 2022.[1115]

However, on 18 January 2022, Unit 2 was shut down for maintenance and refueling, and on the same day NNR granted permission for the steam generator replacement to be carried out during the "current maintenance outage."[1116] During shutdown, Eskom and Framatome conducted a final review prior to steam generator replacement, which concluded that, should the replacement work be carried out, "there is a high likelihood" these operations would not be completed within the planned timeframe. Ultimately, considering the "potential severe impact" of Unit 2 not resuming operation by June 2022 as planned, Eskom announced in March 2022 its decision to defer the replacement until the next planned outage scheduled for August 2023.[1117]

As of June 2022, replacement of the steam generators was still scheduled to start in September 2022 at Unit 1 and August 2023 at Unit 2. Should Eskom fail to fulfill the refurbishment work before the plant's license expires in 2024, NNR may require the station to be shut down pending completion.

Eskom Troubles

Problems with the existing steam generators continue to plague the plant, and in January 2021, Unit 1 was taken offline for several months due to leakages. The unplanned outage of the reactor caused further supply problems for the already struggling Eskom, leading to additional load-shedding.[1118] The load factor of Koeberg-1 dropped to 51 percent in 2021.[1119]

In June 2021, Eskom announced it had suspended the station's General Manager while investigations into the performance of the plant are conducted, stating that "Eskom is currently experiencing load shedding that is affecting the entire country and its economy. One

1113 - Ibidem.

1114 - According to an Eskom spokesperson, personal communication, Anton Eberhard, email dated 13 July 2020; and NNR, "Annual Report 2020/21", 2021, see https://nnr.co.za/wp-content/uploads/2021/11/NNR_Annual-Report_2021-Final.pdf, accessed 5 June 2022.

1115 - NRR, "Annual Report 2020/21", National Nuclear Regulator, 2021; and Chris Yelland, "Nuclear power station life-extension project running late, even before it starts", *Daily Maverick*, 9 January 2022, op. cit.

1116 - NNR, "National Nuclear Regulator (NNR) Update on the Regulatory Oversight of the Koeberg Nuclear Power Station", Press Release, 3 February 2022, see https://nnr.co.za/wp-content/uploads/2022/02/NNR-Media-Release-030222-Nuclear-Safety-Regulatory-Update-on-Koeberg-Oversight.pdf, accessed 5 June 2022.

1117 - *NEI Magazine*, "Eskom defers steam generator replacement at Koeberg until 2023", 7 March 2022, see https://www.neimagazine.com/news/newseskom-defers-steam-generator-replacement-at-koeberg-until-2023-9531601, accessed 16 May 2022.

1118 - *NEI Magazine*, "Koeberg 1 closed after steam generator leakage", 11 January 2021, see https://www.neimagazine.com/news/newskoeberg-1-closed-after-steam-generator-leakage-8446258, accessed 26 June 2021.

1119 - PRIS, "Koeberg-1", IAEA, Updated 12 May 2022, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=836, accessed 11 June 2022.

of Eskom's biggest generating units with a capacity of 900 MW, Koeberg Unit 1 has been on an outage since January 2021, and could have assisted in reducing the depth of loadshedding had the unit been brought back on time as originally planned", adding that while there would be no safety concerns associated, "Eskom leadership has been concerned with outage performance at Koeberg nuclear power plant, and the recent outage on Unit 1 has again been plagued with delays resulting in significant slippage on the return to service date."[1120] It seems reasonable to wonder if and to what extent the wave of resignation among senior technicians occurring at the plant—at a rate that "absolutely horrified" Eskom Chief Operating Officer Jan Oberholzer in October 2021—could also be affecting performance on-site. [1121]

New-build Projects

The state-owned South African utility and Koeberg operator Eskom had considered acquiring additional large PWRs and had made plans to build 20 GW of generating capacity by 2025. However, in November 2008, Eskom scrapped an international tender because the Government was unwilling to provide the loan guarantees demanded by potential financiers, and credit-rating agencies threatened downgrades. In 2011, the Department of Energy (DOE) published an Integrated Resource Plan (IRP) for future power generation investments that contained a 9.6 GW target, or six nuclear units, by 2030. Startup would have been one unit every 18 months beginning in 2022. The total price of the project was estimated to be in the range of US$37-100 billion.[1122]

In March 2016, arguing that "the anticipated South African nuclear new build programme has reached a significant milestone", Eskom filed site license applications for two new nuclear sites at Thyspunt and Duynefountein (also spelled Duynefontyn or Duynefontein) adjacent to the Koeberg site,[1123] and indicated in public information documents filed in 2019 that while the application is intended to evaluate the suitability of the Thyspunt site—this does not include construction and operation yet—the PWR was the selected type of reactor for the project, with no specific design having been chosen yet.[1124] In July 2021, Eskom specified that both sites "remain viable nuclear sites for future electricity power generation", and would continue the application process.[1125] In August and November 2021, NNR held public hearings to resume discussion on the Thyspunt site which, according to Eskom, could host up to 10 GW of nuclear

1120 - Eskom, "Eskom suspends Koeberg Power Stations General Manager for performance-related issues", Press Release, 4 June 2021, see https://www.eskom.co.za/eskom-suspends-koeberg-power-stations-general-manager-for-performance-related-issues/, accessed 4 June 2022.

1121 - Tom Head, "'Horrifying': Eskom fears for Koeberg, as skilled workers ditch nuclear plant", *The South African*, 26 October 2021, see https://www.thesouthafrican.com/news/load-shedding-latest-eskom-nuclear-power-plant-koeberg-no-skilled-workers/, accessed 5 June 2022.

1122 - *NEI Magazine*, "Eskom plans RFP for new reactors by mid-year", 15 March 2017, see https://www.neimagazine.com/news/newseskom-plans-rfp-for-new-reactors-by-mid-year-5761595/, accessed 25 June 2021.

1123 - NNR, "Applications in Progress – NISL Application", NNR Website, Undated, see https://nnr.co.za/applications-in-progress/; and Tembile Sgqolana, "Thyspunt nuke plant plan: For and against band heads", *Daily Maverick*, 27 August 2021, see https://www.dailymaverick.co.za/article/2021-08-27-thyspunt-nuke-plant-plan-for-and-against-bang-heads/, both accessed 5 June 2022.

1124 - Eskom, "Public Information Document in Support of the Eskom Nuclear Installation Site Licence Application for the Thyspunt Site", Authorized 2 September 2019, see https://nnr.co.za/wp-content/uploads/2021/06/English-Nuclear-Installation-Site-Licence-Public-Information-Document.pdf, accessed 5 June 2022.

1125 - Sonal Patel, "South Africa Nuclear Regulator Furthers New Nuclear Build Process", *POWER Magazine*, 2 August 2021, see https://www.powermag.com/south-africa-nuclear-regulator-furthers-new-nuclear-build-process/, accessed 13 June 2022.

capacity. A second round of hearings is planned to begin in the third quarter of 2022.[1126] On 7 June 2022, NNR announced that it is "not in a position to evaluate all factors that either qualifies or disqualifies the Thysunt site as being suitable for siting the postulated nuclear installation design(s)", as the "NNR assessment identified information gaps and outdated data" concluding that "a final decision cannot be made at this stage". Should Eskom choose to complete the process, they have 12 months to submit information and updated data.[1127]

In April 2017, the Western Cape division of South Africa's High Court ruled in favor of two NGOs, the Southern African Faith Communities Environment Institute (SAFCEI) and Earthlife Africa, in their cases against the Government. This halted a December 2015 decision to procure 9.6 GW of new nuclear capacity and annulled the nuclear co-operation agreements that the Government had signed with Russia, South Korea, and the United States. The court concluded that the lack of public consultation on the decisions "rendered its decision procedurally unfair" and breached its statute.[1128] The 2018 Goldman environmental prize was awarded to grassroots activists Makoma Lekalakala and Liz McDaid for the successful legal challenge in this case.[1129]

In January 2018, future President Cyril Ramaphosa said in Davos that "we have no money to go for major nuclear plant building."[1130] Even the Chief Financial Officer of Eskom stated: "I can't go and commit to additional expenditure around a nuclear program."[1131] In August 2018, the Government published its draft IRP 2018[1132], in which new nuclear is absent in the period up to 2030.[1133]

However, in October 2019, in the updated IRP document, lifetime extension of the two Koeberg units was called "critical for continued energy security in the period beyond 2024". The document stated that due to the expected decommissioning of 24 GW of coal capacity, it was proposed to "commence preparations for a nuclear build programme to the extent of 2,500 MW [2.5 GW] at a pace and scale the country can afford because it is a no-regret option in the long term".[1134]

1126 - Parliament of the Republic of South Africa, "Announcements, Tablings and Committee Reports", No. 72—2022, Fourth Session, Sixth Parliament, 17 May 2022, p. 27, see https://www.parliament.gov.za/storage/app/media/Docs/atc/b8b7bf9d-7496-47c9-a615-23f7977893cc.pdf, accessed 11 June 2022.

1127 - NNR, "National Nuclear Regulator (NNR) Update on the Eskom Application for a Nuclear Installation Site Licence for the Thyspunt Site", Stakeholder Update 1/5/6/3 – No:01/22, 7 June 2022, see https://nnr.co.za/wp-content/uploads/2022/06/NNR-STAKEHOLDER-UPDATE-THYSPUNT-NISL-APPLICATION-JUN2022.pdf, accessed 11 June 2022.

1128 - Phil Chaffee, "Legal: High Court Upends South African Newbuild Plans", *Nuclear Intelligence Weekly*, 28 April 2017.

1129 - Jonathan Watts, "Goldman prize awarded to South African women who stopped an international nuclear deal", *The Guardian*, 23 April 2018, see https://www.theguardian.com/world/2018/apr/23/goldman-prize-awarded-to-south-african-women-who-stopped-an-international-nuclear-deal, accessed 25 June 2021.

1130 - Alexis Akwagyiram, "South Africa has no money for major nuclear expansion, Ramaphosa says", *Reuters*, 25 January 2018, see https://www.reuters.com/article/davos-meeting-safrica-nuclear/south-africa-has-no-money-for-major-nuclear-expansion-ramaphosa-says-idINKBN1FE2O4, accessed 25 June 2021.

1131 - *NIW*, "Weekly Roundup", 2 February 2018.

1132 - Despite there being half a dozen versions of the IRP, only one, the revision of 2011 was 'promulgated' so all the other versions including the August 2018 version have no policy status.

1133 - *NEI* Magazine, "South Africa cancels nuclear expansion plans", *Nuclear Engineering International*, 30 August 2018, see https://www.neimagazine.com/news/newssouth-africa-cancels-nuclear-expansion-plans-6728356/, accessed 25 June 2021.

1134 - Department of Mineral Resources and Energy, "Integrated Resource Plan (IRP2019)", October 2019, see http://www.energy.gov.za/IRP/2019/IRP-2019.pdf, accessed 25 June 2021.

In June 2020, the Government issued a "Request for Information" (RfI) to enable an assessment of the potential reactor technologies to be considered under a future newbuild program that might encompass both conventional reactors and SMRs. The vendors were expected to supply technical and financial information by 15 September 2020.[1135] Reportedly, the Government received responses from 25 companies showing interest in some part of the project. The procurement process is scheduled to be completed by 2024.[1136]

In November 2020, the National Energy Regulator of South Africa (NERSA) launched a three-month consultation on the draft plan to construct 2.5 GW of new nuclear capacity by 2030 and beyond. Within the consultation announcement, the regulator stated that it "has not yet formulated any opinions on the issues that are raised in this consultation paper but is raising them so that stakeholders can give their opinions".[1137] Submissions to the consultation highlighted the additional costs of including nuclear power in the power mix. A scenario with additional nuclear and constraint in renewables' expansion was found to cost an additional cumulated R200 billion (US$14 billion) by 2040 compared to a scenario with no nuclear, no increase in coal and unrestricted expansion of renewables.[1138]

Yet, upon analysis of the received material, NERSA announced in September 2021, that it concurred with the draft determination issued by the Minister of Mineral Resources and Energy to launch the process to add 2.5 GW of new nuclear capacity.[1139] A request for proposal for 2.5 GW was to be issued at the end of March 2022.[1140] In mid-April 2022, Energy Minister Gwede Mantashe told reporters: "We are going to send out the proposals." Asked about the timing, Mantashe said: "The sooner the better … we are going to do it."[1141]

National Infrastructure Plan 2050

In March 2022, the Government published "Phase I" of the "National Infrastructure Plan 2050" (NIP 2050),[1142] which states that the IRP 2019 document "will need revision and updating to adequately account for the pace of global innovation and cost reductions realised in the renewable energy sector in determining the least-cost electricity plan for the country", and forecasts "energy supply will be increasingly dominated by renewable energy resources

1135 - Roger Murray and Phil Chaffee, "South Africa: Government RFI Keeps New Nuclear Option Alive", *NIW*, 19 June 2020.

1136 - *WNN*, "South Africa planning to start nuclear procurement", *World Nuclear News*, 22 September 2021, see https://www.world-nuclear-news.org/Articles/South-Africa-planning-to-start-nuclear-procurement, accessed 5 May 2022.

1137 - *NEI Magazine*, "South African regulator launches consultation on new nuclear", 26 November 2020, see https://www.neimagazine.com/news/newssouth-african-regulator-launches-consultation-on-new-nuclear-8380496/, accessed 25 June 2021.

1138 - Helen Suzman Foundation, "Comments to NERSA on the ministerial determination of October 2020 regarding the commencement of a process to procure 2 500MW of new nuclear generation capacity", 3 February 2021, see https://hsf.org.za/publications/submissions/comments-by-hsf-to-nersa-on-ministerial-determination-3-february-2021.pdf, accessed 26 June 2020.

1139 - NERSA, "NERSA's Concurrence with the Ministerial Determination on the Procurement of 2 500MW Generation Capacity from Nuclear Technoogy", Press Release, National Energy Regulator of South Africa, 3 September 2021, see https://www.nersa.org.za/wp-content/uploads/bsk-pdf-manager/2021/09/Media-Statement-NERSAs-concurrence-with-the-ministerial-determination-on-the-procurement-of-2-500MW-generation-capacity-from-Nuclear-technology.pdf, accessed 6 June 2022.

1140 - David Dalton, "Deputy Minister Confirms Plans For 2,500 MW Of New Nuclear", *NucNet*, 23 September 2021, op. cit.

1141 - Ed Stoddard, "Mantashe sends clear signal SA will tender for nuclear power proposals as soon as possible", *Daily Maverick*, 12 April 2022, see https://www.dailymaverick.co.za/article/2022-04-12-mantashe-sends-clear-signal-sa-will-tender-for-nuclear-power-proposals-as-soon-as-possible/, accessed 27 June 2022.

1142 - Department of Public Works and Infrastructure, "National Infrastructure Plan 2050 (NIP 2050) Phase I", *Government Gazette*, No. 46033, Government of South Africa, 11 March 2022, see https://www.gov.za/sites/default/files/gcis_document/202203/46033gon1874.pdf, accessed 5 June 2022.

– especially wind and solar, which are least cost and where South Africa has an advantage", adding that "off-grid innovations such as micro-grid solutions will increasingly contribute to electrification".

Based on the Council for Scientific and Industrial Research (CSIR) technical report from 2020—which extends the IRP analysis to 2050 – NIP 2050 says that the least-cost path would have 57 percent of solar and wind in the installed capacity. However, CSIR did not include new nuclear in its projections and stated that

> regardless of CO_2 ambition, renewable energy is expected to play an increasingly important role whilst other new-build low-carbon energy providers like nuclear, CSP [Concentrating Solar Power] and coal (with CCS [Carbon Capture and Storage]) are not part of the least-cost energy mix.[1143]

Yet NIP 2050 labels the introduction of SMRs as a "game changer in the future energy planning" and maintains the inclusion of new nuclear in the future energy mix, arguing that "no economy of the world can be powered wholly from renewables, there is room for co-existence of baseload energy source such as nuclear and renewables in so called hybrid energy systems…". According to the document, the country

> should embrace the global recognition of nuclear as a clean energy source as already acknowledged in the Nuclear Energy policy of 2008 and the IRP 2019 and take cue from economies of the world that are already compliant with the Paris Agreement on Climate Change through either aggressive deployment of nuclear (planned or installed).

It is unclear to what "economies of the world" the document is referring to.

The NIP 2050 proposes to allocate a portion of the electricity price to "research and development for advanced and innovative nuclear energy systems such as small modular reactors [SMRs]."[1144]

Eskom has been short of funding for a long time. As of February 2022, Eskom was R392 billion (US$25.9 billion) in debt, with the Budget Minister announcing that to date the government has contributed R136 billion (US$9 billion) to pay off debt, committing to a further R88 billion (US$5.8 billion) until 2025–26, adding "We have been focusing on fixing Eskom for 13 years, it can't be right. They will have to sell assets".[1145]

Credit-Rating Agency Fitch stated in December 2021 that Eskom "received over 80% of all government support to financially distressed state-owned companies over the past decade" and, while acknowledging significant state support, confirmed Eskom's rating at 'B', deep in "junk territory" (highly speculative).[1146]

1143 - Jarrad Wright and Joanne Calitz, "Technical Report—Systems analysis to support increasingly ambitious CO2 emissions scenarios in the South African electricity system ", CSIR, 15 July 2020, see https://researchspace.csir.co.za/dspace/bitstream/handle/10204/11483/Wright_2020.pdf, accessed 5 June 2022.

1144 - Department of Public Works and Infrastructure, "NIP 2050 Phase I", 11 March 2022, op. cit.

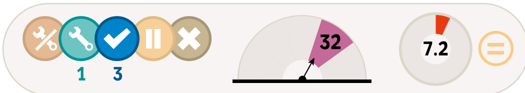
1145 - Ron Derby, "Budget 2022: Finance minister calls on Eskom to sell assets to solve its debt issues", *Mail & Guardian*, 23 February 2022, see https://mg.co.za/business/2022-02-23-budget-2022-finance-minister-calls-on-eskom-to-sell-assets-to-solve-its-debt-issues/, accessed 6 June 2022.

1146 - Fitch Ratings, "Fitch Revises Eskom's Outlook to Stable; Affirms at 'B'", 21 December 2021, see https://www.fitchratings.com/research/corporate-finance/fitch-revises-eskom-outlook-to-stable-affirms-at-b-21-12-2021, accessed7 June 2022.

In November 2021, the European Commission announced the "Just Energy Transition Partnership" seeing France, Germany, the U.K., the U.S., and the European Union pledge to secure US$8.5 billion in funding to help finance South Africa's transition away from coal, through various mechanisms (including grants, concessional loans and investments, and risk sharing instruments, as well as the mobilization of the private sector).[1147] There is no mention of nuclear power.

THE AMERICAS

Argentina



Argentina has three nuclear reactors that provided 10.2 TWh of electricity in 2021, a slight increase over the 10 TWh produced the previous year, which represented 7.2 percent of the country's electricity generation (compared to the maximum of 19.8 percent in 1990). They were all supplied by foreign reactor builders. Atucha-1 and -2 were built by German company Siemens, and the CANDU (CANadian Deuterium Uranium) type reactor at Embalse by Canadian Atomic Energy of Canada Limited (AECL).

In April 2018, the regulatory authority gave a lifetime extension license to enable Atucha-1, originally started up in 1974, to continue operating until 2024, which thus allows for a 50-year working life.[1148] 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 refurbishment work to be carried out once the reactor is taken offline upon expiration of its current license. Refurbishment is expected to take two years and cost US$463 million.[1149]

Atucha-2 was ordered in 1979 and construction was stop/start over the following decades, but finally, grid connection occurred on 27 June 2014. It took until 26 May 2016 to enter commercial operation.[1150] Performance has been mediocre in the past three years with increasing but still very low load factors, according to IAEA-PRIS, of respectively 29 percent (2019), 40 percent (2020), and 58 percent (2021).[1151]

1147 - EU Commission, "France, Germany, UK, US and EU launch ground-breaking International Just Energy Transition Partnership with South Africa", European Commission, Press Release, 2 November 2021, see https://ec.europa.eu/commission/presscorner/detail/en/IP_21_5768, accessed 10 June 2022.

1148 - *WNN*, "Atucha 1 operating licence renewed", 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" ["Atucha I Operating License extended to 2024"], 12 April 2018, see http://www.na-sa.com.ar/prensa/atucha-i-extendi-su-licencia-de-operaci-n-hasta-2024/, accessed 15 April 2018.

1149 - NA-SA, "Nucleoeléctrica Argentina firmó el Acuerdo Marco de Licenciamiento para la operación a largo plazo de la Central Nuclear Atucha I" ["Nucleoeléctrica Argentina signed the Licensing Framework Agreement for the long-term operation of the Atucha I Nuclear Power Plant"], Press Release, 1 July 2022, see https://www.na-sa.com.ar/es/prensa/nucleoelectrica-argentina-firmo-el-acuerdo-marco-de-licenciamiento-para-la-operacion-a-largo-plazo-de-la-central-nuclear-atucha-i-283, accessed 17 August 2022.

1150 - *WNN*, "Atucha 2 receives full operating licence", 31 May 2016, see http://www.world-nuclear-news.org/RS-Atucha-2-receives-full-operating-licence-3105165.html, accessed 7 May 2021.

1151 - IAEA-PRIS, "Reactor Details, Atucha-2", IAEA, Updated 12 May 2022, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=5, accessed 16 June 2022.

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.[1152] In August 2019, the ARN renewed the operating license for ten years to 2029.[1153]

The Atucha-3 Saga

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.[1154] 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 co-operation 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.[1155] 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.[1156]

The total cost of the Hualong and Atucha-3 projects were expected to be US$12.5 billion (other sources indicate US$15 billion)[1157] financed with 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.[1158]

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."[1159] 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[1160], which did not happen. Argentina now aims to start construction by the end of 2022.[1161]

1152 - WNA, "Nuclear Power in Argentina", January 2021, see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx, accessed 7 May 2021.

1153 - ARN, "La ARN otorgó la Licencia de Operación para el segundo ciclo de la Central Nuclear Embalse", 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.

1154 - *WNN*, "Argentina-China talks on new nuclear plants", 8 May 2015, see https://www.world-nuclear-news.org/Articles/Argentina-China-talks-on-new-nuclear-plants, accessed 17 June 2022.

1155 - 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.

1156 - Phil Chaffee, "Argentina", *Nuclear Intelligence Weekly*, 29 September 2017.

1157 - *WNN*, "Argentina and China sign contract for two reactors", 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.

1158 - Phil Chaffee, "The Fallout From Argentina's Newbuild Retreat", *Nuclear Intelligence Weekly*, 25 May 2018.

1159 - Cassandra Garrison and Hugh Bronstein, "Argentine official, in China, talks nuclear deal and soymeal", *Reuters*, 25 June 2019, see https://www.reuters.com/article/us-argentina-china-idUSKCN1TQ221, accessed 17 June 2022.

1160 - *WNN*, "China confident of 'new era' for nuclear, says CNNC president", 9 October 2019, see https://world-nuclear-news.org/Articles/China-confident-of-new-era-for-nuclear-says-CNNC, accessed 7 May 2021.

1161 - *NEI Magazine*, "Argentina optimistic about nuclear ties with China", 28 April 2022, see https://www.neimagazine.com/news/newsargentina-optimistic-about-nuclear-ties-with-china-9658784, 17 June 2022.

The future of the project remains nevertheless uncertain, and its prospects are further diminished by the ongoing tensions between the U.S. and China, which may 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".[1162] The two main companies that have developed the Hualong One, CNNC and China General Nuclear Power Corporation (CGN), were indeed blacklisted by the U.S. Administration.[1163]

In June 2021, the state-owned company Nucleoeléctrica Argentina SA (NA-SA) approved its Action Plan for the coming years.[1164] The plan still provides 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.[1165] 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,[1166] appears eager to disqualify China from this cooperation. In May 2022, according to NA-SA President José Luis Antúnez, the U.S. 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 warning over safety concerns raised by the alleged immaturity of the Hualong design and past issues with the technology.[1167]

The concerns raised by the US 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 is 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.[1168]

Argentina appears willing to move forward, with NA-SA President arguing 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."[1169] A contract was signed in February 2022,

1162 - 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.

1163 - 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.

1164 - 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.

1165 - 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.

1166 - Anna Isaac, "US celebrates 'win' as Britain looks to push China out of nuclear energy sites", *The Independent,* 29 September 2021.

1167 - *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.

1168 - *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.

1169 - *CE Noticias Financieras*, "U.S. lobby to block Argentine nuclear power production", 22 May 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".[1170] "Details of financing of the nuclear power plant deal were not available" according to *Reuters*.[1171]

In April 2022, NA-SA President José Luis Antúnez indeed confirmed that while the contract has been signed, both parties still "have to close the financial agreement – the credit details and the disbursement schedule". [1172] 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.[1173] Antúnez 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,[1174] contractually a 90 months-timeline has been set before first criticality.[1175]

Argentina's inflation rate has exceeded 70 percent in July 2022 making financing of large, long-term projects particularly hazardous.[1176]

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 had estimated that the construction would cost US$105 million,[1177] but by construction start in 2014 estimates had risen to US$446 million.[1178] In 2019, it was rescheduled to begin operating in 2022.[1179] That will 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

1170 - CNEA, "Se firmó el contrato para la construcción de la Central Nuclear Atucha III" ["The Contract for the construction of Atucha III Nuclear Power Plant was signed"], Comisión Nacional de Energía Atómica (in Spanish), 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. See also *WNN*, "China and Argentina sign nuclear project deal", 2 February 2022, see https://www.world-nuclear-news.org/Articles/China-and-Argentina-sign-nuclear-project-deal, accessed 2 February 2022.

1171 - Shivani Singh and Adam Jourdan, "China inks $8 bln nuclear power plant deal in Argentina", *Reuters*, 2 February 2022, see https://www.reuters.com/business/energy/china-inks-nuclear-power-plant-deal-with-argentina-2022-02-02/, accessed 2 June 2022.

1172 - *NEI Magazine*, "Argentina optimistic about nuclear ties with China", 28 April 2022, op. cit.

1173 - 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.

1174 - *NEI Magazine*, "Argentina optimistic about nuclear ties with China", 28 April 2022, op. cit.

1175 - Phil Chaffee, "Atucha-3 EPC Contract Remains Conditional", Interview with José Luis Antúnez, NA-SA, *NIW*, 11 February 2022.

1176 - 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.

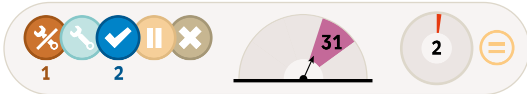
1177 - IAEA, "Technology Roadmap for Small Modular Reactor Deployment", August 2021, see https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1944_web.pdf, accessed 4 July 2022.

1178 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2021.

1179 - *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.

also announced that the current schedule aims for a 2027-startup.[1180] 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".[1181] In 2021, a non-profit organization established by the Group of Twenty (G20), GI Hub, reported their own estimate at US$750 million.[1182] Even at the lower cost estimate of US$520 million, the per unit cost of the project is around US$17,000/kW, roughly twice the cost estimate of the most expensive Generation-III reactors. For more details, see Small Modular Reactors (SMRs) – Argentina.

Brazil



Brazil operates two nuclear reactors that provided the country with a stable 13.9 TWh or 2.4 percent of its electricity in 2021, less than half of the maximum of 4.3 percent in 2001. Both units are operated by state controlled Eletronuclear at the Central Nuclear Almirante Alvaro Alberto (CNAAA) site. The construction of a third reactor at CNAAA was suspended in late 2015, but work is planned to be resumed.

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. But in October 2020, Westinghouse signed a contract to conduct engineering analyses critical to safety, reliability, and long-term operation to be part of the program to extend its working life until 2044.[1183] As of September 2020, the process was expected to cost BRL1.2 billion (US$$_{2020}$230 million).[1184] In June 2022, the IAEA completed a Safety Aspects of Long Term Operation (SALTO) follow-up mission at the plant concluding that preparation work was progressing "in a timely manner". A full scope SALTO mission is expected to take place in 2023.[1185]

Angra-2 is a large PWR German-designed reactor with a capacity of 1,275 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 require a 20-year extension.[1186]

1180 - *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.

1181 - Ibidem.

1182 - 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.

1183 - 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.

1184 - Judith Perera, "Nuclear development in Brazil", *NEI*, 16 September 2020, see https://www.neimagazine.com/features/featurenuclear-development-in-brazil-8137143/, accessed 17 June 2022.

1185 - IAEA, "IAEA Concludes Long Term Operational Safety Review at Brazil's Angra Nuclear Power Plant", Press Release 107/2022, 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.

1186 - 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.

Until 2015, spent fuel storage capacity was to be extended through the extension of wet storage in pools. But in February 2016, Eletronuclear presented as its new strategy the construction of a dry storage facility at the CNAAA site at a projected cost of US$62.5 million.[1187] As of December 2018, spent fuel pools were filled to 81 percent at Angra-1, and to 70 percent at Angra-2. In 2019, the Government warned that "considering realistic assumptions", storage capacity of the spent fuel pools of both units would be exhausted by mid-2021.[1188]

In 2017, Eletronuclear contracted Holtec to construct a dry storage facility designed to host 72 casks—known as the Complementary Dry Storage Unit for Spent Fuel or UAS (Unidade de Armazenamento a Seco)—supply 15 storage devices, and adjust Angra-1 and -2 facilities to enable the transfer of the spent fuel assemblies.[1189] The facility officially entered its expected 50-year operation on 22 March 2021—on schedule despite the pandemic—when the first canisters containing spent fuel from Angra-2 were loaded into a module and placed in the facility.[1190]

On 25 March 2021, the regulator (CNEN– Comissão Nacional de Energia Nuclear) issued a two-year operation authorization to UAS.[1191] To make room for a further five years of reactor operation, 288 used fuel elements from Angra-2 were transferred into nine casks placed in the facility in May–October 2021 with transfer of 222 fuel elements from Angra-1 starting in February 2022.[1192] The spent fuel is not considered waste, and storage allows for "the possibility of future reuse".[1193]

The Angra-3 Saga

Preparatory work for the construction of Angra-3 started in 1984, although 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 started on 1 June 2010.

In early 2011, the Brazilian national development bank (BNDES) approved a BRL6.1 billion (US$3.6 billion) loan for work on the project and in November 2013, Eletrobras Eletronuclear signed a €1.25 billion (US$$_{2013}$1.67 billion) contract with French builder AREVA for the

1187 - Electronuclear, "Implementation of the Spent Fuel Complementary Dry Storage Unit – UAS", 24 August 2016, see https://www.aben.com.br/Arquivos/467/467.pdf, accessed 26 June 2022.

1188 - Government of the Federal Republic of Brazil, "Convention on Nuclear Safety Report by the Government of the Federal Republic of Brazil for the Eighth Review Meeting in March/April 2020—Eight National Report of Brazil", August 2019, p. 182, see https://www.gov.br/cnen/pt-br/avulsos/8th_National_Report_of_Brazil_2019.pdf/@@download/file/8th_National_Report_of_Brazil_2019.pdf, accessed 24 June 2022.

1189 - Ibidem.

1190 - *WNN*, "First fuel loaded into Brazilian dry storage facility", 5 May 2021, see https://world-nuclear-news.org/Articles/First-fuel-loaded-into-Brazilian-dry-storage-facil, accessed 24 June 2022.

1191 - CNEN, "CNEN autoriza operação da Unidade de Armazenamento Complementar a Seco para Combustíveis Irradiados (UAS) da CNAAA", Comissão Nacional de Energia Nuclear, Federal Government of Brazil, Press Release (in Portuguese), 26 March 2021, see https://www.gov.br/cnen/pt-br/assunto/ultimas-noticias/cnen-autoriza-operacao-da-unidade-de-armazenamento-complementar-a-seco-para-combustiveis-irradiados-uas-da-cnaaa, accessed 25 June 2022.

1192 - *NEI Magazine*, "Brazilian dry storage facility begins operation", 6 May 2021, see https://www.neimagazine.com/news/newsbrazilian-dry-storage-facility-begins-operation-8725959, accessed 25 June 2022.

1193 - CNEN, "CNEN autoriza operação da Unidade de Armazenamento Complementar a Seco para Combustíveis Irradiados (UAS) da CNAAA", Press Release (in Portuguese), 26 March 2021, op. cit.

completion of the plant.[1194] Commissioning was planned for July 2016 but was first delayed in April 2015 to May 2018—without explanation.[1195]

Later in 2015, an ongoing corruption probe led to a series of arrests among plant personnel, contractors, politicians, and senior Eletronuclear executives, and by February 2016, a new deadline for startup of mid-2019 was "already being reevaluated" due to the collapse of funding for the project and further impact of the investigation.[1196] By then, the budget had already risen to about US$5.2 billion, according to *Nuclear Engineering International*.[1197]

The political scandals surrounding the project culminated in March 2019 with the arrest of former Brazilian President Michel Temer for allegedly diverting BRL1.8 billion (US$475 million) from Eletronuclear's Angra-3 new-build project[1198] (see also earlier WNISR editions).

The case is still unfolding. In June 2020, a probe to investigate potential fraud at Eletronuclear was launched, with the police executing "18 search and seize warrants and 12 prison orders". Reportedly, fraud and corruption "appeared to involve companies in and out of Brazil" and undue payments in at least six contract signed by Eletronuclear were discovered.[1199] Since then, several incriminated personalities saw the charges against them dropped for "lack of evidence", the latest being former president of Eletronuclear Pedro José Diniz Figueiredo, as the company announced in April 2022.[1200] Former President Temer was acquitted earlier in February 2022 along with former president of Eletronuclear Othon Luiz Pinheiro da Silva and six other defendants.[1201] Later in the month, Eletrobras (Centrais Elétricas Brasileiras S.A.)—parent company of Eletronuclear—announced it would be reimbursed US$26 million as part of a leniency agreement reached with conglomerate Andrade Gutierrez for its role in the corruption scheme that afflicted the project.[1202] Nonetheless, the contracts for the construction work were declared void in 2017.[1203]

In June 2020, the same month the fraud investigation was launched, the Government approved plans for completing the project, "with or without a partner joining Eletronuclear." This is despite Eletronuclear's various statements at the time that an additional BRL14.5–15 billion

1194 - *WNN*, "Areva contracted to complete Angra 3", 8 November 2013, see http://www.world-nuclear-news.org/C-Areva-contracted-to-complete-Angra-3-081134.html, accessed 7 May 2021.

1195 - *NIW*, "Briefs – Brazil", *Nuclear Intelligence Weekly*, 9 January 2015.

1196 - Anthony Venezia, "Brazil: Politics, Corruption and Finances Grind Angra-3 to a Halt", *NIW*, 19 August 2016.

1197 - *NEI Magazine*, "Brazil's Angra 3 could resume construction in 2018", 23 January 2017, see https://www.neimagazine.com/news/newsbrazils-angra-3-could-resume-construction-in-2018-5722003/, accessed 16 June 2022.

1198 - *NIW*, "Brazil: 'Radioactivity' Probe Nets Ex-President; Shoot-Out Near Angra", *Nuclear Intelligence Weekly*, 22 March 2019.

1199 - Vladislav Pekic, "Fraud investigation launched into Angra-3 contracts: Brazilian police", *Nucleonics Week*, S&P Global, 9 July 2020; and Rodrigo Viga Gaier and Carolina Mandl, "Brazil's Eletrobras under investigation for potential fraud - filing", *Reuters*, 25 June 2020, see https://www.reuters.com/article/eletrobras-investigation-idLTASoN2E000C, accessed 15 June 2022.

1200 - Eletronuclear, "Police close investigation against former Eletronuclear president", Eletrobras, Press Release, 27 April 2022, see https://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Pol%C3%ADcia-arquiva-inqu%C3%A9rito-contra-ex-presidente-da-Eletronuclear.aspx, accessed 15 June 2022.

1201 - *CE Notificas Financieras*, "Temer and seven others acquitted in case that led to his arrest", 6 February 2022.

1202 - Marta Nogueira and Carolina Pulice, "CORRECTED-Brazil's Eletrobras wins $26 mln from Andrade Gutierrez graft deal", *Reuters*, 5 February 2022, see https://www.reuters.com/article/energy-eletrobras-andrade-idUSL6N2UF072, accessed 15 June 2022.

1203 - *NEI Magazine*, "Contracts for work at Brazil's Angra 3 declared void", 6 February 2017, see https://www.neimagazine.com/news/newscontracts-for-work-at-brazils-angra-3-declared-void-5732236, accessed 15 June 2022.

(US$$_{2020}$2.65–2.9 billion) of investment would be needed to complete the unit,[1204] which is said to be about 65 percent complete,[1205] with 80 percent of the equipment bought and stored, costing about BRL 25 million (US$4.5–4.9 million) per year in "upkeep and insurance".[1206]

In March 2021, Eletrobras approved a "Critical Path Acceleration Plan" to complete Unit 3 of the Angra nuclear power plant by 2023,[1207] at the time Leonardo Mendes Cabral, director of privatizations at BNDES, said he expects 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.[1208] Reportedly, BRL 7–8 billion (US$1.4–1.6 billion) have already been invested in the past.[1209]

In June 2021, BNDES released a statement 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 lead 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.[1210]

Meanwhile, in March 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 will be completed by 2023 and enter commercial operation in November 2026.[1211]

In July 2021, Eletronuclear announced that a consortium made up of Ferreira Guedes, Matricial and ADtranz had won the tender with a winning bid of BRL292 million (US$56.1 million).[1212] In February 2022, a contract was signed with the consortium, allowing to "soon" restart construction, according to Eletronuclear.[1213]

1204 - 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.

1205 - *WNN*, "Contract signed allowing resumption of Angra 3 works", 10 February 2022, see https://www.world-nuclear-news.org/Articles/Contract-signed-to-allow-resumption-of-Angra-3-wor, both accessed 15 June 2022.

1206 - *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.

1207 - Ibidem.

1208 - *WNN*, "Brazil to complete Angra 3 finance package in 18 months, says BNDES director", 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.

1209 - *NEI Magazine*, "Eletronuclear signs a contract to resume construction of Angra 3", 15 February 2022, see https://www.neimagazine.com/news/newseletronuclear-signs-a-contract-to-resume-construction-of-angra-3-9481356/, accessed 19 June 2022.

1210 - Vladimir Pekic, "Brazil's BNDES bank hires consortium to shape Angra-3 project", *Nucleonics Week*, Platts, 1 July 2021.

1211 - *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.

1212 - *NEI Magazine*, "Consortium chosen for preliminary work to complete Angra 3", 29 July 2021, see https://www.neimagazine.com/news/newsconsortium-chosen-for-preliminary-work-to-complete-angra-3-8945927, accessed 16 June 2022.

1213 - *WNN*, "Contract signed allowing resumption of Angra 3 works", 10 February 2022, see https://www.world-nuclear-news.org/Articles/Contract-signed-to-allow-resumption-of-Angra-3-wor, accessed 17 June 2022.

A consortium presentation dated May 2022 indicates that on-site construction is planned to resume in the third quarter 2022. The document prepared by Angra Eurobras NES encloses a provisional schedule which now projects commissioning of the unit in December 2026 and commercial operation in February 2028.[1214] An additional BRL19.4 billion (US$3.9 billion) is said to be needed to complete the project.[1215]

Eletrobras Privatization Key to Angra-3 Project

Concurrently to progress on the Angra-3 project and after six years of uncertainty, successive setbacks and controversy, the Government finalized the privatization of Eletrobras, the biggest power company in Brazil and parent entity of Eletronuclear. The capitalization of Eletrobras was said to be crucial to the completion of Angra-3, with BNDES President Gustavo Montezano arguing in April 2022 that without privatization, "there is a chance that Angra 3 may not be completed", stating that the cost would fall unto the company and the Brazilian public.[1216]

Requirements for the privatization to move forward included some major restructuring designed to maintain Eletronuclear under state control, since the Federal Constitution defines nuclear energy as a "matter of national security".[1217] On 10 September 2021, a new state agency—Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A. (ENBpar)—was created by presidential decree to take over Eletrobras' activities "that cannot be privatized".[1218] On 4 January 2022, the Ministry of Mines and Energy, which controls ENBpar, announced that the new agency was "activated", thus allowing the privatization of Eletrobras to proceed.[1219]

The Eletrobras privatization overcame the final legal hurdle in May 2022[1220] and was launched on 14 June 2022 when the newly issued shares started trading on the stock exchange—one of the largest share offerings in the country this year—designed to dilute the Brazilian government's stake from 72 to 45 percent.[1221]

Institutional Changes and New-Build Plans

Further institutional changes include the creation of a new agency to improve the independence of the nuclear regulator. A decree signed by President Jair Bolsonaro in May 2021 provided for

1214 - 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.

1215 - *CE Noticias Financieras*, "Angra 3 nuclear power plant needs R$19.4 billion to be ready", 17 May 2022.

1216 - *bnamericas*, "Failure of Eletrobras privatization could make Angra 3 unviable – BNDES", *Business News Americas*, 7 April 2022.

1217 - *CE Noticias Financieras*, "The Federal Audit Court approves privatization, learn what the next steps will be", 18 May 2022.

1218 - 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.

1219 - 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.

1220 - Michael Pooler, "Eletrobras privatisation plan wins approval from Brazil court", *Financial Times*, 19 May 2022, see https://www.ft.com/content/7856998b-3ad5-4bb7-b7a2-d8554efc938e, accessed 17 June 2022.

1221 - *AFP*, "Eletrobras goes private with Bolsonaro bell ring", *Agence France Press*, as published by *rfi*, 14 June 2022, see https://www.rfi.fr/en/eletrobras-goes-private-with-bolsonaro-bell-ring, accessed 17 June 2022.

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.[1222]

In November 2021, at COP26, Minister of Mines and Energy Bento Costa Lima said the country would add 10 GW of nuclear power over the next 30 years,[1223] as envisaged by the "National Energy Plan to 2050" or PNE 2050 (Plano Nacional de Energia 2050) approved by the Government in December 2020.[1224] 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 unveils 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.[1225] While no location has been named yet, the 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.[1226]

This echoes past announcements, with Eletronuclear's CEO Dos Santos Guimarães saying in September 2020 that "We started this work [a "Brazilian Nuclear Atlas" of all potential sites] a long time ago but it was stopped. However, with the movement we have now through the National Energy Plan we will go ahead to select a site and technology for a new plant." Research at the time was conducted with EPE, the Federal University of Rio de Janeiro and GARTA (Group for Analysis of Environmental Technologic Risk).[1227]

In June 2022, Eletronuclear also signed a five-year Memorandum of Understanding (MoU) with French utility EDF to promote cooperation in the development of nuclear energy projects, which expands the scope of a past MoU to "emerging" technologies, including Small Modular Reactors (SMRs) and hydrogen.[1228]

1222 - 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.

1223 - 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.

1224 - MME and EPE, "PNE 2050 — Plano Nacional de Energia", Ministry of Mines and Energy and Energy Research office, Federal Government of Brasil, 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%20Energia%20Nuclear.pdf#search=nuclear, accessed 16 June 2022.

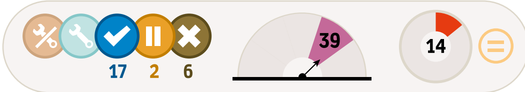
1225 - EPE, "Plano Decenal de Expansão de Energia 2031", Energy Research Office, Ministry of Mines and Energy, Federal Government of Brazil, 2022 (in Portuguese), see https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/Documents/PDE%202031_RevisaoPosCP_rvFinal.pdf, accessed 16 June 2022; and 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.

1226 - 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.

1227 - *NEI*, "Nuclear development in Brazil", 16 September 2020, op. cit.

1228 - 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, accessed 17 June 2022.

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 and they are considered in LTO, leaving 17 reactors in operation. In 2021, these produced 86.8 TWh that constituted 14.3 percent of total electricity generation. Eighteen out of the 19 nuclear reactors are located in the province of Ontario, where nuclear power constituted 34 percent of installed capacity and contributed 58 percent of the electricity generated in 2021.[1229]

Most of Canada's electricity comes from renewable sources. According to Statistics Canada, renewables contributed 66 percent of the total electricity generated in 2021, the same as the 2020 share.[1230] Renewable electricity is dominated by hydro power, which contributed over 60 percent of all of Canada's electricity generation; wind energy contributed modest 5.8 percent, and solar energy only 0.4 percent. Over the past decade 2012–2021, Canada's total renewable electricity generating capacity has grown from 84.4 GW to 102.9 GW, with hydropower increasing from 75.5 GW to 82.7 GW, wind from 6.2 GW to 14.3 GW, and solar from 0.8 GW to 3.6 GW.[1231] This does not include off-grid power sources.

Projections by the Canadian Energy Regulator (previously the National Energy Board) expect the nuclear share of total electricity generation decreasing to 11.5 percent in 2050 in the "business-as-usual" scenario, now referred to as the "Current Policies" scenario.[1232] In the "Evolving Policies" scenario that foresees greater policy action on climate change over time, and the construction of SMRs in Ontario and New Brunswick, the nuclear share declines only slightly further, to around 11 percent in 2050. In contrast, in the same scenario, wind and solar energy are projected to supply around 29 percent of all electricity by 2050, although demand grows by 49 percent. Nonetheless, the report's findings imply that even the "Evolving Policies" scenario is "unlikely to achieve net-zero emissions by 2050." In addition, the Canadian Energy Regulator considered six Net Zero Electricity scenarios; in five of these scenarios, installed nuclear power capacity is projected increase by somewhere between 7 GW and 15 GW.

Both the "Current Policies" and "Evolving Policies" scenarios assume that all the current nuclear refurbishment projects aimed at extending the reactors' operational lifetime for another 30 years are successfully completed. In 2017, Ontario's Financial Accountability Office also highlighted four key financial risks to ratepayers, including "the risk that the cost of refurbishing the reactors will be higher or lower than planned", "that the cost of operating the reactors will be higher or lower than planned", the "risk of insufficient electricity grid demand for nuclear generation" and "the risk that the Province's commitment to nuclear refurbishment

1229 - IESO, "Power Data – Supply Overview: Transmission-Connected Generation", Independent Electricity System Operator, 2022, see https://ieso.ca/en/Power-Data/Supply-Overview/Transmission-Connected-Generation, accessed 7 May 2022.

1230 - Statistics Canada, "Electric Power Generation, Monthly Generation by Type of Electricity", Table 25-10-0015-01, Government of Canada, Last Modified 7 July 2021, 2022, see https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501&pickMembers%5B0%5D=1.1&pickMembers%5B1%5D=2.1&cubeTimeFrame.startMonth=01&cubeTimeFrame.startYear=2021&cubeTimeFrame.endMonth=12&cubeTimeFrame.endYear=2021&referencePeriods=20210101%2C20211201, accessed 7 May 2022.

1231 - IRENA, "Renewable Capacity Statistics 2022", International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

1232 - Canada Energy Regulator, "Canada's Energy Future 2021", April 2022, see https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/index.html, accessed 7 May 2022.

will preclude it from taking advantage of alternative, lower cost, low emissions grid-scale electricity generation options".[1233]

The last risk is already being realized in Ontario. In 2018, the National Energy Board (now Canadian Energy Regulator) assumed that the prices for wind and solar power in 2020 would be respectively CAD1,541/kW (US$$_{2018}$1,193) and CAD 1,613/kW (US$$_{2018}$1,248/kW).[1234] The actual figures for 2020 reported in the 2021 report are CAD 1,389/kW(US$$_{2020}$1,087/kW) for wind and CAD 1,516/kW (US$$_{2020}$1,186/kW) for solar power.[1235] Despite this faster than expected decline in costs, Ontario's Independent Electricity System Operator (IESO) is not planning for any significant expansion for wind or solar power in its annual planning documents.[1236] In a report published in October 2021, IESO appears to have suppressed or deleted a scenario that showed costs to ratepayers would decline by 8 percent if Ontario switched to meeting its generation needs with a mix of energy storage, increased energy efficiency and additional wind capacity.[1237]

As of now, only one of the four Darlington reactors (Unit 2) has been refurbished, albeit with a delay of around four months. The unit was reconnected to the grid in June 2020.[1238] The refurbishments of Darlington Unit 3 and Unit 1 have commenced and according to the Q1 2022 update from Ontario Power Generation, the expected completion dates are Q1 2024 and Q2 2025 respectively.[1239] Refurbishment of Darlington Unit 4 is expected to start in Q3 2023 and is expected to be completed by Q4 2026. These dates are reproduced in IESO's 2021 planning document.[1240] (See also Table 11.)

1233 - FAO, "Nuclear Refurbishment—An Assessment of the Financial Risks of the Nuclear Refurbishment Plan", Financial Accountability Office of Ontario, November 2017, see https://www.fao-on.org/web/default/files/publications/Nuc%20Refurb%20nov%202017/Nuclear-Refurb-EN.pdf, accessed August 2022.

1234 - NEB, "Canada's Energy Future 2018—An Energy Market Assessment—Energy Supply and Demand Projections to 2040", October 2018, see https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/archive/2018/2018nrgftr-eng.pdf, accessed 9 August 2022.

1235 - Canada Energy Regulator, "Canada's Energy Future 2021", op. cit., p.29,

1236 - IESO, "Annual Planning Outlook—Ontario's electricity system needs: 2023-2042", Independent Electricity System Operator, December 2021, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Dec2021/2021-Annual-Planning-Outlook.ashx, accessed 18 May 2022; and IESO, "Annual Planning Outlook—Ontario's electricity system needs: 2022-2040", December 2020, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Dec2020.ashx; also 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.

1237 - Matthew McClearn, "Documents raise questions about costs to retire Ontario's natural gas power plants", *The Globe and Mail*, 15 April 2022.

1238 - OPG, "Darlington's refurbished Unit 2 reactor returns to service", Press Release, 4 June 2022, see https://www.opg.com/media_release/darlingtons-refurbished-unit-2-reactor-returns-to-service/, accessed 10 August 2022.

1239 - OPG, "Darlington Refurbishment performance update – Q1 2022", Ontario Power Generation, 16 June 2022, see https://www.opg.com/strengthening-the-economy/our-projects/darlington-refurbishment/, accessed 10 August 2022.

1240 - IESO, "Annual Planning Outlook—Ontario's Electricity System Needs: 2023-2042", December 2021, op. cit.

Table 11 – Status of Canadian Nuclear Fleet - PLEX and Expected Closures

Reactor	Operator	Grid Connection	Refurbishment[a]	Planned Closure[b]	Licensed to[c]
Bruce-1	Bruce	1977	Restarted in 2012	2064	2028
Bruce-2		1976	Restarted in 2012		
Bruce-3		1977	01/02/23–30/06/26		
Bruce-4		1978	01/01/25–31/12/27		
Bruce-5		1984	01/07/26–30/06/29		
Bruce-6		1984	17/01/20–05/11/23		
Bruce-7		1986	01/07/28–30/06/31		
Bruce-8		1987	01/07/30–30/06/33		
Darlington-1	OPG	1990	15/02/22–18/04/25	2055	2025
Darlington-2		1990	10/16–06/20[d]		
Darlington-3		1992	30/07/20–02/01/24		
Darlington-4		1993	15/09/23–16/10/26		
Pickering-1	OPG	1971		30/09/2024[e]	2028[f]
Pickering-4		1973		13/12/2024[e]	
Pickering-5		1982		31/12/2025[e]	
Pickering-6		1983		31/12/2025[e]	
Pickering-7		1984		31/12/2025[e]	
Pickering-8		1986		31/12/2025[e]	
Point Lepreau	NB Power	1982	03/2008–03/2012	2039–2040[g]	2032[h]

Sources: Compiled by WNISR, from IESO, Operators, CNSC, 2022

Notes: **OPG** = Ontario Power Generation

(a) - IESO, "Annual Planning Outlook - A view of Ontario's electricity system needs", Independent Electricity System Operator, 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; Updated with IESO, "Annual Planning Outlook - Ontario's electricity system needs: 2022-2040", December 2020, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Dec2020.ashx, accessed 12 June 2021; and IESO, "Annual Planning Outlook - Ontario's electricity system needs: 2023-2042", December 2021, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Dec2021/2021-Annual-Planning-Outlook.ashx, accessed 18 May 2022.

(b) - As announced by operator.

(c) - As listed on Canadian Nuclear Safety Commission's (CNSC) website for each station.
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) - Refurbishment of Darlington-2 was completed in June 2020, with the reactor being reconnected to the grid on 2 June 2020. 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.

(e) - Pickering Units 1 and 4 are expected to be closed in 2024, and Units 5–8 in 2025. OPG, "The future of Pickering Generating Station", n.d., see https://www.opg.com/powering-ontario/our-generation/nuclear/pickering-nuclear-generation-station/future-of-pickering/, accessed 12 June 2021.

(f) - The Pickering Power Plan is licensed to 2028 but operation beyond 2024 would require additional authorizations. CNSC, "Pickering Nuclear Generating Station, Updated 24 February 2022, see https://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm, accessed 17 August 2022.

(g) - 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; 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.

(h) - 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.

These work schedules are all slightly delayed. IESO's annual planning document from January 2020, listed the refurbishment completion dates for Darlington-1, Darlington-3, and Darlington-4 as 15 December 2024, 15 June 2023, and 31 May 2026 respectively.[1241] In July 2022, OPG issued a CAD300 million nuclear green bond to finance the refurbishment of the Darlington reactors.[1242]

At the Bruce site, refurbishment of Unit 6 has been ongoing since January 2020; in December 2021, the last of eight new steam generators was installed.[1243] Refurbishment of Unit 3 is due to start in "early 2023".[1244]

The only nuclear power plant that is not to be refurbished is the Pickering plant with six operating reactors. According to Ontario's IESO, these are scheduled to be closed between September 2024 and December 2025.[1245] Despite a major advocacy effort by pronuclear advocates, in particular "Canadians for Nuclear Energy, which is largely funded by power workers' unions", the Ontario government does not appear to be considering extending their operations beyond 2025.[1246]

In June 2022, the Canadian Nuclear Safety Commission (CNSC) extended the license for the Point Lepreau nuclear generating station in New Brunswick, the only nuclear power plant outside the province of Ontario, for a period of ten years to June 2032.[1247] The plant's operator, NB Power, had sought an unprecedented 25-year license extension, which was opposed by a number of civil society groups.[1248]

Federal government agencies and some provincial governments continue to promote the development of Small Modular Reactors (see chapter on SMRs).

1241 - IESO, "Annual Planning Outlook—A View of Ontario's Electricity System Needs", January 2020, op. cit.

1242 - OPG, "OPG Issues Inaugural Nuclear Green Bond", Press release, 15 July 2022, see https://www.opg.com/media_releases/opg-issues-inaugural-nuclear-green-bond/, accessed 18 September 2022.

1243 - Bruce Power, "Final steam generator lift for Unit 6 Major Component Replacement complete", Press Release, 20 December 2021, see http://www.brucepower.com/2021/12/20/final-steam-generator-lift-for-unit-6-major-component-replacement-complete/, accessed 7 May 2022.

1244 - Bruce Power, "Bruce Power to advance Unit 3 Major Component Replacement in 2023", 17 March 2022, see https://www.brucepower.com/2022/03/17/bruce-power-to-advance-unit-3-major-component-replacement-in-2023/, accessed 7 May 2022.

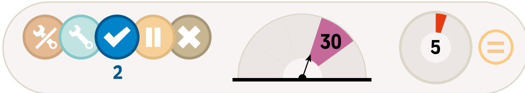
1245 - IESO, "Annual Planning Outlook—Ontario's Electricity System Needs: 2023-2042", December 2021, op. cit., p.31.

1246 - Jessica McDiarmid, "Pickering nuclear station is closing as planned, despite calls for refurbishment", *Canada's National Observer*, 29 July 2022, see https://www.nationalobserver.com/2022/07/29/news/pickering-nuclear-station-closing-despite-calls-refurbishment, accessed 30 July 2022.

1247 - CNSC, "CNSC renews the power reactor operating licence for the Point Lepreau Nuclear Generating Station for a 10-year period", Canadian Nuclear Safety Commission, 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 22 June 2022.

1248 - *The Canadian Press*, "NB Power seeks unprecedented 25-year licence for Point Lepreau nuclear power station", as published by *CTV News*, 24 January 2022, see https://atlantic.ctvnews.ca/nb-power-seeks-unprecedented-25-year-licence-for-point-lepreau-nuclear-power-station-1.5751903, accessed 24 January 2022; CELA, "Climate Change Concerns Breezed Over on Final Day of Nuclear Licensing Hearing for Point Lepreau Nuclear Power Plant", Canadian Environmental Law Association, 12 May 2022, see https://cela.ca/blog-climate-change-concerns-breezed-over-on-final-day-of-nuclear-licensing-hearing-for-point-lepreau-nuclear-power-plant/, accessed 30 July 2022.

Mexico



Laguna Verde, located in Alto Lucero, Veracruz, is the only nuclear power plant in Mexico. Two General Electric (GE) reactors 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,[1249] bringing the plant's net capacity to 1.55 GW.[1250] The plant is owned and operated by the state utility Federal Electricity Commission (Comisión Federal de Electricidad - CFE). Nuclear production reached 11.6 TWh and represented 5.3 percent of total production.[1251]

The Energy Transition Act provides for target shares of "clean energy"—nuclear power is included—in the total electricity production. The goal was 30 percent for 2021 with 29.5 percent achieved—including 3.5 percent nuclear—35 percent in 2024, and 42 percent in 2036.

CFE applied for a 30-year lifetime extension to allow for the two Laguna Verde reactors to operate for a total of 60 years.[1252] In March 2019, the IAEA completed a Safety Aspects of Long-Term Operation (SALTO) review mission at the plant and, as part of the process, made the recommendation to extend the operating lives of the reactors. The license renewal was granted in July 2020 to allow for the operation of Unit 1 until July 2050.[1253] The license for Unit 2 will expire in April 2025, and the renewal process is underway.[1254]

At the time of the 2019-IAEA mission, plant management requested for a SALTO follow-up mission to be scheduled for 2021,[1255] the mission took place on 21–24 June 2022.[1256] The team noted that further work is necessary by 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".[1257]

1249 - *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.

1250 - PRIS, "Country Statistics—Mexico", IAEA, Updated 12 May 2022, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=MX , accessed 2 June 2022.

1251 - The percentage of 5.3% is from IAEA-PRIS data. According to the Mexican Ministry of Energy (SENER) data, nuclear production represented 3.5 percent of the total production of electricity. Secretariat of Energy, "Programa para el Desarrollo del Sistema Eléctrico Nacional 2022–2036", Secretaría de Energía, Government of Mexico (in Spanish), May 2022, see http://www.gob.mx/sener/articulos/programa-para-el-desarrollo-del-sistema-electrico-nacional-304042, accessed 2 June 2022.

1252 - *NEI Magazine*, "IAEA reviews long term operation of Mexico's Laguna Verde", 25 March 2019, see https://www.neimagazine.com/news/newsiaea-reviews-long-term-operation-of-mexicos-laguna-verde-7057990/, accessed 7 May 2021.

1253 - Secretaría de Energía, "La Secretaría de Energía renueva la licencia de operación a Unidad 1 de la Central Nuclear Laguna Verde", 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.

1254 - William Freebairn, "Mexico's energy ministry approves 30-year license extension for nuclear unit", *S&P Global*, 20 July 2020, see https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/072020-mexicos-energy-ministry-approves-30-year-license-extension-for-nuclear-unit, accessed 5 May 2022.

1255 - 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.

1256 - IAEA, "IAEA Concludes Long Term Operational Safety Review at Mexico's Laguna Verde Nuclear Power Plant", 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.

1257 - Ibidem.

Media reports point to frequent problems, often age-related, at the Laguna Verde plant.[1258] In November 2021, the Spanish daily *EL PAÍS* obtained leaked documents and reported an event at the plant, following the loss of external power affecting Unit 2 on 30 October 2021 and the automatic switch to emergency diesel generators.[1259] CFE stated that Unit 2 was in cold shutdown during the event, confirmed that the emergency diesels started up but denied plant safety had been compromised at any point.[1260] Between 2012 and 2020, Laguna Verde recorded 33 unusual events, according to CFE data.[1261]

In 2010, CFE presented various scenarios for the country's energy future, including one that projected the construction of ten reactors by 2028.[1262] In December 2019, it was reported that CFE was considering the construction of an additional four reactors, two at the existing site at Laguna Verde—an idea that has been around for years without any follow-up—and two on the Pacific coast. While the current government has regularly promoted such newbuild programs and claimed to be working on the various options—including a Small Modular Reactor (SMR) in Sonora or Baja California—none has been officially settled on. In June 2021, Manuel Bartlett Díaz, director of CFE, appeared to confirm that the engineering and analysis work had been completed, but expressed reluctance in investing in new nuclear, mentioning long construction times and high investment cost as potentially contrary to current priorities.[1263] Nonetheless, in December 2021, Energy Minister Norma Rocío Nahle García announced before Congress that the government still feels positive about the perspective of a newbuild program, mentioning that the project would take "around 6 to 7 years to materialize" after basic engineering.[1264]

In a "Trend Analysis" of Mexico's energy sector published in March 2022, the 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."[1265]

On 31 May 2022, the Government published its "Program for the Development of the National Electricity System 2022–2036", which forecasts that with an addition of 2.5 GW, nuclear will

1258 - *El Universal*, "Laguna Verde: could a nuclear accident put Mexico at risk of becoming the next Chernobyl?", *The Yucatan Times*, 9 April 2021, see https://www.theyucatantimes.com/2021/04/laguna-verde-could-a-nuclear-accident-put-mexico-at-risk-of-becoming-the-next-chernobyl/, accessed 26 June 2021.

1259 - Emilio Godoy, "Alerta roja en la central nuclear de Laguna Verde por un apagón", *EL PAÍS* (in Spanish), 6 November 2021, see https://elpais.com/mexico/2021-11-06/un-nuevo-apagon-vuelve-a-poner-la-mira-en-la-central-nuclear-de-laguna-verde.html, accessed 1 June 2022.

1260 - CFE, "A la opinión Pública", Press Release (in Spanish), Comisión Federal de Electricidad/Federal Electricity Commission, 6 November 2021, see https://app.cfe.mx/Aplicaciones/OTROS/Boletines/boletin?i=2379, accessed 2 June 2022.

1261 - Eddie Corp, "The damage cornered the Laguna Verde nuclear plant | Economy", *Digis Mak*, 1 February 2021, see https://digismak.com/the-damage-cornered-the-laguna-verde-nuclear-plant-economy/, accessed 26 June 2021.

1262 - *POWER*, "New Nuclear Projects for Turkey, Jordan, and Mexico", 19 May 2010, see https://www.powermag.com/new-nuclear-projects-for-turkey-jordan-and-mexico/; and Robert Campbell, "Mexico eyes up to 10 new nuclear plants by 2028", *Reuters*, see https://www.reuters.com/article/us-mexico-nuclear-idUSTRE64B6CF20100512, both accessed 1 June 2022.

1263 - Arturo Solís, "CFE enfría su interés por más energía nuclear en México", *Forbes* (in Spanish), 18 June 2021, see https://www.forbes.com.mx/cfe-enfria-su-interes-por-mas-energia-nuclear-en-mexico/, accessed 6 May 2022.

1264 - Cas Biekmann, "New Publicly Owned Nuclear Project Begins to Materialize", *Mexico Business*, 9 December 2021, see https://www.forbes.com.mx/politica-reforma-electrica-no-es-ideologia-y-no-se-esta-corriendo-a-privados-nahle/; and Patricia Tapia Cervantes, "Reforma eléctrica no es ideología y no se está corriendo a privados: Nahle", *Forbes* (in Spanish), 6 December 2021, see https://www.forbes.com.mx/politica-reforma-electrica-no-es-ideologia-y-no-se-esta-corriendo-a-privados-nahle/, both accessed 1 June 2022.

1265 - Fitch Solutions, "Industry Trend Analysis - Natural Gas Remains Mexico's Dominant Power Type Amid Nuclear And Non-Hydro Uncertainties", 15 March 2022.

contribute about six percent to the increase of the overall installed capacity between 2026 and 2036—versus 25 percent for solar and 13 percent for wind—despite this nuclear's share in net installed capacity mix in 2036, will still be around 2.5 percent, due to increased demand assumed in the scenarios.[1266]

United States

See Focus Countries – United States Focus.

ASIA AND MIDDLE EAST

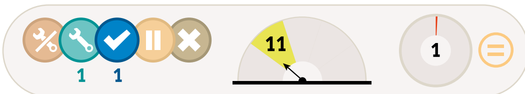
China

See Focus Countries – China Focus.

India

See Focus Countries – India Focus.

Iran



Iran's nuclear program was launched in the 1950s with the support of the U.S. under the Atoms for Peace program. It operates one nuclear reactor (Bushehr-1) with a net capacity of 915 MWe, which was connected to the grid in 2011 and became commercially operational in 2013. Originally a German project, the design was later converted to a Russian VVER-1000.

In 2021, Bushehr-1 generated 3.24 TWh which represents less than 1 percent of electricity generated in the country. This is substantially below the 2020 generation of 5.8 TWh. The reasons for the decline are unclear.

In 2014, the Atomic Energy Organisation of Iran (AEOI) reportedly reached a preliminary agreement with Russia's Rosatom to build two additional nuclear power reactors at Bushehr.[1267] Work on Bushehr-2, "officially" restarted in 2017, but the first pour of new concrete was only in 2019.[1268] The original construction start of Bushehr-2 had taken place on 1 February 1976 but work was interrupted in 1978.

1266 - SENER, "Programa para el Desarrollo del Sistema Eléctrico Nacional 2022–2036", Secretaría de Energía/Secretariat of Energy, Government of Mexico (in Spanish), 31 May 2022, see http://www.gob.mx/sener/articulos/programa-para-el-desarrollo-del-sistema-electrico-nacional-304042, accessed 2 June 2022.

1267 - *WNN*, "Russia, Iran discuss further reactors", 14 March 2014, see https://www.world-nuclear-news.org/NN-Russia-Iran-discuss-further-reactors-1403144.html, accessed 1 August 2022.

1268 - 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.

"Levelling" work on the area selected for the 3rd reactor started in January 2021.[1269] According to Iranian officials, these two reactors are to be completed in 2024 and 2026.[1270] Considering that Bushehr-1's official start of construction was 1 May 1975, and it was connected to the grid only in 2011, these dates seem ambitious. In fact, in June 2022, according to Mohammad Eslami, Director of AEOI, the construction process had witnessed a 28-month delay.[1271]

In the summer of 2022, AEOI announced that it had "started another project to build a completely Iranian nuclear power plant with a capacity of 360 MWe" at a new site called Darkhovin in southwest Iran.[1272] Like other new reactor designs, this one is also delayed. The first announcement about this design and this site was reiterated in 2008, as AEOI officials also announced a target of 20,000 MW of nuclear power capacity by 2020.[1273] Although announced as its own design, in reality AEOI worked jointly with "some European companies" but this stopped "when sanctions were intensified" against Iran.[1274] Former officials also admitted that "it will take a rather long time" for the reactor to be completed.

Iran continued negotiations over the future of the Joint Comprehensive Plan of Action (JCPOA), a 2015-international agreement on the Iranian nuclear program reached by Iran and China, France, Germany, Russia, the United Kingdom, and the United States, but as of the time of this writing, no definite settlement had been reached. In June 2022, the IAEA announced that it "could not confirm the completeness and correctness of the Iran's declaration under its Comprehensive Safeguards Agreement" and subsequently Iran informed the IAEA that 27 extra cameras that were installed as part of the JCPOA would be removed.[1275]

Over the past decade, Iran's renewable energy capacity has increased from 9.9 GW in 2012 to 11.9 GW in 2021, which constituted around 14 percent of the installed capacity in the country.[1276] The bulk of this is hydropower, but Iran also had installed 310 MW of wind capacity (up from 106 MW in 2012) and 456 MW of solar capacity (up from zero in 2012). Together, non-hydro renewables contributed 1.8 TWh of electrical energy to the grid, which constituted around 0.51 percent of all electricity.[1277]

1269 - *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.

1270 - Ibidem.

1271 - *NEI Magazine*, "Iran begins concrete pouring for wall at Bushehr 2", *Nuclear Engineering International*, 28 June 2022, see https://www.neimagazine.com/news/newsiran-begins-concrete-pouring-for-wall-at-bushehr-2-9806133, accessed 7 July 2022.

1272 - *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 31 July 2022.

1273 - 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 23 August 2022.

1274 - *NEI Magazine*, "Iran Begins Work on Domestic-Design NPP", 5 July 2022, op. cit.

1275 - *WNN*, "Iran to remove monitoring cameras", *World Nuclear News*, 10 June 2022, see https://world-nuclear-news.org/Articles/Iran-to-remove-monitoring-cameras, accessed 30 July 2022.

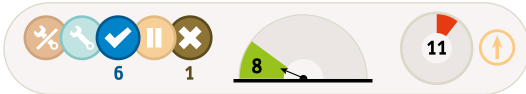
1276 - IRENA, "Renewable Capacity Statistics 2022", International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

1277 - BP, "Statistical Review of World Energy 2022", June 2022, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 12 July 2022.

Japan

See Focus Countries – Japan Focus.

Pakistan



Pakistan operates six nuclear reactors with a combined capacity of 3.3 GW. Nuclear electricity production in Pakistan has increased significantly from 9.6 TWh in 2020 to 15.8 TWh in 2021 mainly due to the startup of a new reactor early in the year. The share of electricity from nuclear power plants increased from 7.1 percent in 2020 to 10.6 percent in 2021. Both production and share numbers are historic maxima.

Operating reactors now also include Kanupp-3 (or Karachi-3), which was connected to the grid in March 2022 and is the second Hualong-One reactor to become operational outside of China.[1278] The sister unit, Kanupp-2, was connected to the grid a year earlier, in March 2021. Both reactors were built outside Karachi by the China National Nuclear Corporation (CNNC). CNNC also constructed the four operating CNP-300 nuclear reactors in Chashma and continues to assist with operations and maintenance.[1279] In 2017, CNNC and the Pakistan Atomic Energy Commission (PAEC) signed a cooperation agreement on constructing a Hualong One reactor at Chashma.[1280]

Kanupp-1, a CANDU reactor imported from Canada, was closed in August 2021. The 50-year old unit was closed after decades of poor performance, with a lifetime load factor of a mere 29.5 percent. Following that closure, all of Pakistan's nuclear power plants are now from China. These reactor imports are reported to have contributed to major financial problems, and the repayment of foreign and local loans has become a challenge.[1281] Analysts have also highlighted safety concerns, especially due to the location of the plant near a city of over 22 million inhabitants.[1282]

Pakistan renewable energy capacity has grown from 7.1 GW in 2012 to just under 12.9 GW in 2021.[1283] Wind and solar capacity have grown from around 0.06 GW and 0.05 GW in 2012 to 1.3 GW and 1.1 GW respectively in 2021. According to Pakistan's National Electric Power Regulatory Authority, generation from wind, solar, and biomass contributed respectively 2.2 percent, 0.55 percent, and 0.54 percent to the country's total electricity generation

1278 - Khaleeq Kiani, "K-3 nuclear power plant connected to national grid", *Dawn*, 5 March 2022, see https://www.dawn.com/news/1678278, accessed 7 May 2022.

1279 - CNNC, "Chinese overseas nuclear power unit passes final acceptance", China National Nuclear Corporation, Updated 10 December 2019, see https://en.cnnc.com.cn/2019-12/10/c_446316.htm, accessed 7 May 2022.

1280 - *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 7 May 2022.

1281 - 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 7 May 2022.

1282 - Chelsey Dulaney, "Chinese reactor sparks concerns in Pakistan", *Deutsche Welle*, 22 April 2022, see https://www.dw.com/en/chinese-reactor-sparks-concerns-in-pakistan/av-61559609, accessed 7 May 2022.

1283 - IRENA, "Renewable Capacity Statistics 2022", International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

during Fiscal Year 2020–21.[1284] Hydropower contributed around 30 percent. BP reports that wind energy generation went up from 2.7 TWh in 2020 to 3.4 TWh in 2021, and solar energy generation went up from 1.2 TWh to 1.5 TWh during the same period.[1285]

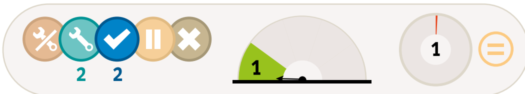
South Korea

See Focus Countries – South Korea Focus.

Taiwan

See Focus Countries – Taiwan Focus.

United Arab Emirates



The United Arab Emirates (UAE) is building four APR-1400 reactors at Barakah with a total generation capacity of 5.6 GW. Of these, construction of two units has been completed and they have entered commercial operation in April 2021 and March 2022 respectively.[1286] They were connected to the grid in August 2020 and in September 2021 respectively. In 2021, the two reactors generated a combined 1.8 TWh or 1.3 percent of the country's electricity.

As of June 2022, the overall project was said to be 97 percent complete according to the Emirates Nuclear Energy Corporation (ENEC).[1287] The Barakah project is financed through a joint venture agreement between Korea Electric Power Company (KEPCO) and ENEC.

In November 2021, ENEC announced that Barakah-3 was scheduled to start electricity production in 2023 and, in June 2022, confirmed that fuel loading was underway after its subsidiary and operator of the plant, Nawah Energy Company, had been granted an operating license from the Federal Authority for Nuclear Regulation (FANR).[1288] In July 2022, ENEC announced that Unit 4 had completed hot functional testing.[1289]

These reactors are all delayed compared to initial projections. In 2014, ENEC had projected that Unit 1 would "enter commercial operation in 2017, Unit 2 in 2018, Unit 3 in 2019 and the final

1284 - NEPRA, "State of Industry Report 2021", National Electric Power Regulatory Authority, Islamic Republic of Pakistan, 2022, see https://nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202021.pdf, accessed 13 September 2022.

1285 - BP, "Statistical Review of World Energy 2022—71st Edition", June 2022, op. cit.

1286 - Su Xiapo, "UAE adds 1,400 megawatts of nuclear energy to national electricity grid", *The Star*, 25 March 2022, see https://www.thestar.com.my/news/world/2022/03/25/uae-adds-1400-megawatts-of-nuclear-energy-to-national-electricity-grid, accessed 10 June 2022.

1287 - *TradeArabia News Service*, "Work on UAE's Barakah nuclear project nearing completion", *ZAWYA*, 6 June 2022, see https://www.zawya.com/en/projects/construction/work-on-uaes-barakah-nuclear-project-nearing-completion-kk8gwx3r, accessed 6 June 2022.

1288 - ENEC, "At COP 26, ENEC Continues to Deliver Clean Energy Transition with Unit 3 Construction Completion of the Barakah Nuclear Energy Plant", Press Release, 4 November 2021, see https://www.enec.gov.ae/news/latest-news/at-cop-26-enec-continues-to-deliver-clean-energy-transition-with-unit-3-construction-completed/, accessed 14 November 2021; and ENEC, "Fuel Assemblies loading started at Unit 3 of the Barakah Plant after Receiving Operating License from FANR", Press Release, 19 June 2022, see https://www.enec.gov.ae/news/latest-news/fuel-assemblies-loading-started-at-unit-3-of-barakah-plant-after-receiving-operating-license/, accessed 10 August 2022.

1289 - *WNN*, "Barakah 4 completes hot functional tests", 21 July 2022, *World Nuclear News*, see https://world-nuclear-news.org/Articles/Barakah-4-completes-hot-functional-tests, accessed 10 August 2022.

Unit 4 in 2020".[1290] As discussed in earlier WNISR editions, the delays are primarily due to four factors: challenges in establishing and training a domestic workforce; the discovery of voids in the containment buildings of Units 2 and 3; delays in commissioning reactors in South Korea; and quality assurance scandals within South Korea's nuclear industry. Considering the fact that Barakah is South Korea's first nuclear project abroad and UAE is a newcomer country, the delays remain remarkably limited.

In October 2021, Barakah was the site of an IAEA's Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency Exercise, which simulated a significant release of radioactive substances into the atmosphere.[1291] As of mid-2022, the results of the exercise had not been published. However, an independent assessment of the risks of cesium-137 dispersal from spent nuclear fuel fires at Barakah and Iran's Bushehr nuclear plant found that these could result in widespread contamination.[1292] In the case of Barakah, which presents "a considerably larger threat" because of its "large wet storage facilities", the analysis found that several major cities in Gulf countries would be "at risk" of receiving "levels of fallout that would contaminate food and water supplies and require relocating large numbers of people".[1293]

Although there has been talk about further cooperation with South Korea on nuclear power, there are no concrete plans to build any more nuclear reactors in the UAE.[1294] The aim of that cooperation could be rather "to identify potential prospects to support the establishment of nuclear energy projects in other countries".[1295]

Meanwhile, UAE's renewable generation capacity has increased rapidly. Over the past decade, total capacity went from 13 MW in 2012 to 2,706 MW in 2021, almost entirely composed of solar energy.[1296] The UAE's "Energy Strategy 2050" launched in 2017 targets 50 percent of clean energy, out of which 44 percent would be derived from renewables and 6 percent from nuclear power.[1297] In December 2020, the UAE submitted its revised Nationally

1290 - ENEC, "Unit 1 of power plant more than 57% complete", Emirates Nuclear Energy Corporation, Press Release, 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.

1291 - NEA, "NEA participation in ConvEx-3 exercise", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, 3 November 2021, see https://www.oecd-nea.org/jcms/pl_61791/nea-participation-in-convex-3-exercise; and *ExpatMedia*, "UAE continues nuclear drill at Barakah nuclear plant", 27 October 2021, see https://www.expatmedia.net/uae-continues-nuclear-drill-barakah-nuclear-plant/2021/10/, both accessed 30 July 2022.

1292 - Thomas G. A. S. Spence and Ali Ahmad, "Risks to Persian Gulf Cities from Spent Fuel Fires at the Barakah and Bushehr Nuclear Power Plants", *Science & Global Security*, Vol. 29, Issue 2, 4 May 2021.

1293 - Ibidem.

1294 - *Yonhap*, "S. Korea, UAE discuss cooperation on nuclear power, new energy resources", *Yonhap News Agency*, 31 May 2022, see https://en.yna.co.kr/view/AEN20220531005700320, accessed 10 June 2022; and ENEC, "UAE Delegation to Seoul, Korea: ENEC and KEPCO discuss Joint Venture Commitments and Future Cooperation in the Nuclear Sector", 3 June 2022, see https://www.enec.gov.ae/news/announcements/uae-delegation-to-seoul-korea-enec-and-kepco-discuss-joint-venture-commitments/, accessed 10 August 2022.

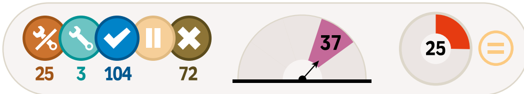
1295 - *WNN*, "South Korea and UAE to collaborate on new nuclear opportunities", *World Nuclear News*, 11 September 2019, see https://www.world-nuclear-news.org/Articles/South-Korea-and-UAE-to-collaborate-on-new-nuclear, accessed 17 August 2022.

1296 - IRENA, "Renewable Capacity Statistics 2022", International Renewable Energy Agency, April 2022, see https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed 14 April 2022.

1297 - United Arab Emirates Government, "UAE Energy Strategy 2050", Updated 1 May 2021, see https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/federal-governments-strategies-and-plans/uae-energy-strategy-2050, accessed 10 May 2021.

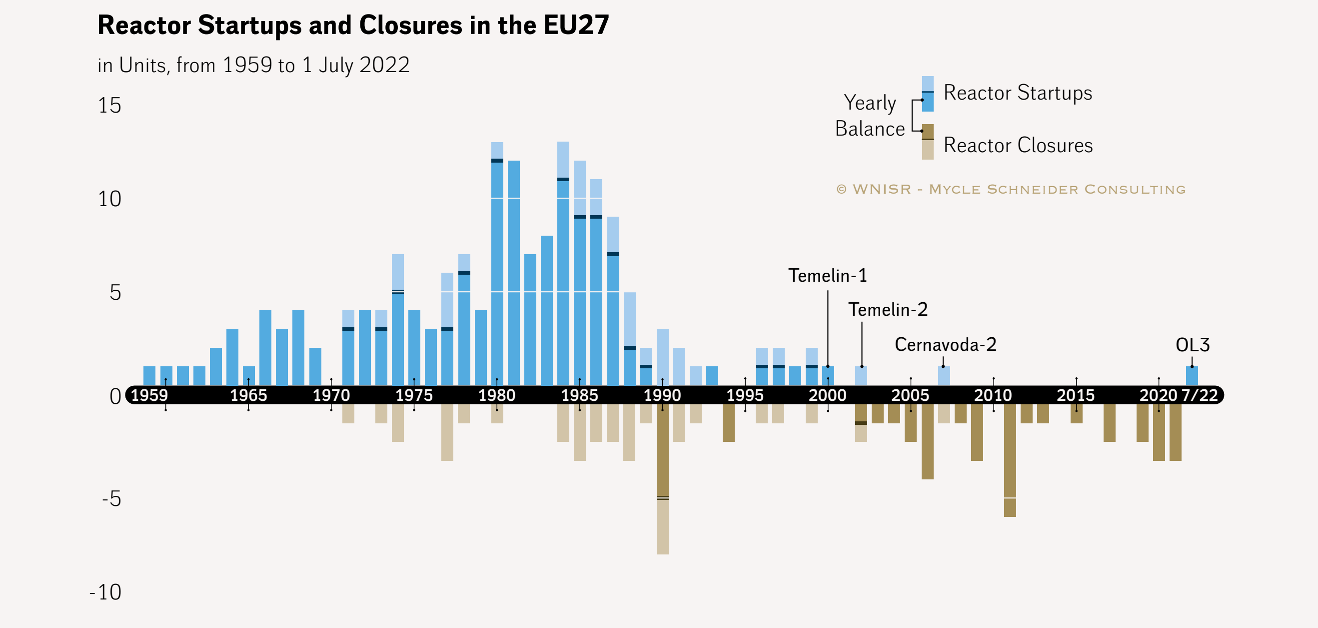
Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) reaffirming these targets.[1298]

EUROPEAN UNION (EU27)



The EU27 member states have gone through three nuclear construction waves (see Figure 64)—two small ones in the 1960s and the 1970s and a larger one in the 1980s (mainly in France). But since 1992, in more than thirty years, only 13 reactors were connected to the grid in current EU27 Member States, about half of them in France and one in Finland, the rest in Eastern and Central Europe. Only three reactors started up since 2002: one each in the Czech Republic, Romania, and Finland. After Cernavoda-2 was connected to the grid in Romania in 2007, the next and latest reactor—the long-awaited, many times delayed Olkiluto-3—only produced its first kilowatt-hours in March 2022.

Figure 64 · Nuclear Reactors Startups and Closures in the EU27 1959–1 July 2022



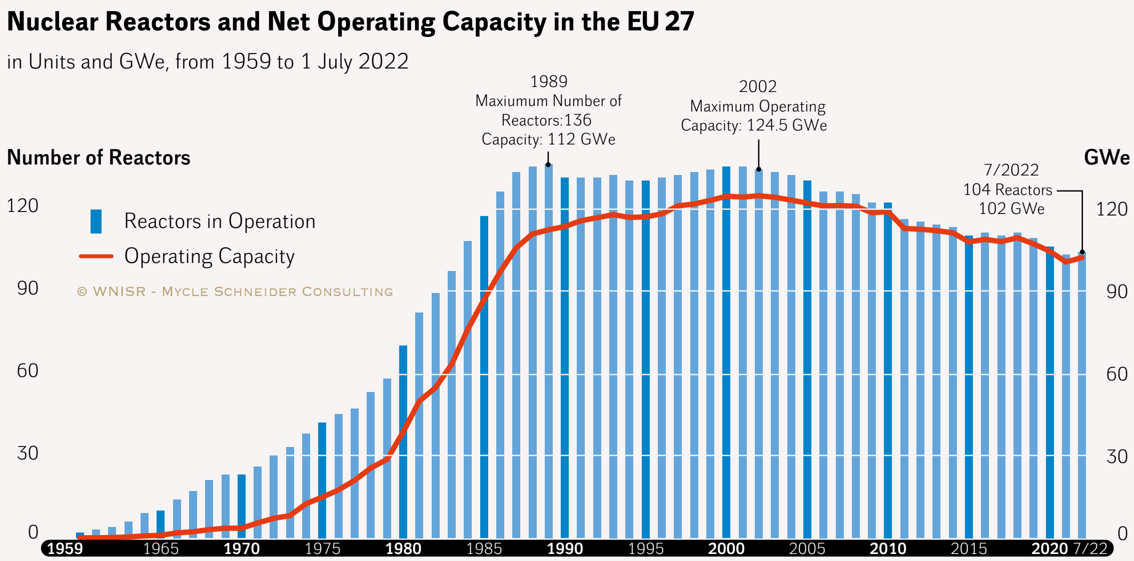
Sources: WNISR, with IAEA-PRIS, 2022

As Figure 65 shows, 104 reactors are operating in the EU27 as of mid-2022, 32 less than the historic maximum of 136 units in 1989. The vast majority of the operating plants, 85 units or over 80 percent, are located in seven of the western countries—with 56 units, almost two thirds, in France alone—and only 19 in the six newer member states with nuclear power.

The closure of Brokdorf, Grohnde, and Gundremmingen-C, in December 2021, brings the number of permanently closed reactors in the EU27 to 72 (63 in Western Europe, over half of which in Germany). Thirty-four units were closed since 2000.

1298 - UAE, "Second Nationally Determined Contribution of the United Arab Emirates", United Arab Emirates, December 2020, see https://unfccc.int/sites/default/files/NDC/2022-06/UAE%20Second%20NDC%20-%20UNFCCC%20Submission%20-%20English%20-%20FINAL.pdf, accessed 10 August 2022.

Figure 65 · Nuclear Reactors and Net Operating Capacity in the EU27



Sources: WNISR, with IAEA-PRIS, 2022

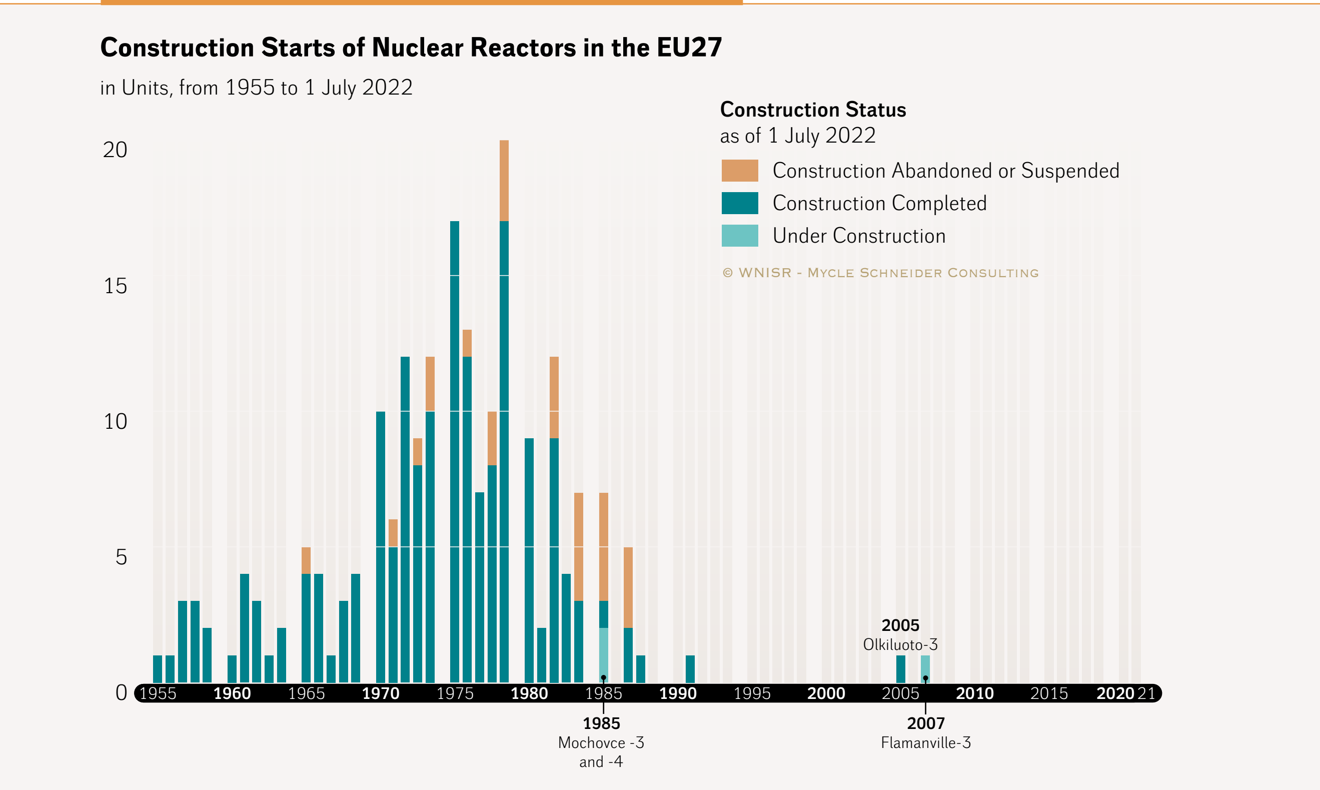
In the EU27, in 2021, nuclear plants have generated 699 TWh, a 7-percent increase compared to the previous year. While the nuclear share in net power production is not yet available, BP indicates a 25.3 percent share in gross generation (24.6 percent in 2020).[1299]

In the absence of any significant delivering new-build program (see Figure 66), the average age of nuclear power plants keeps increasing since the mid-80s and at mid-2022 stands at 36.6 years (see Figure 67 and Figure 68). The three reactors under construction, two in Slovakia (since 1985) and one in France (since 2007), will not significantly change this evolution.

The age distribution shows that now over 86 percent—90 of 104—of the EU's operating nuclear reactors have been in operation for 31 years and beyond, of which 30 have been on the grid for 41 years and more.

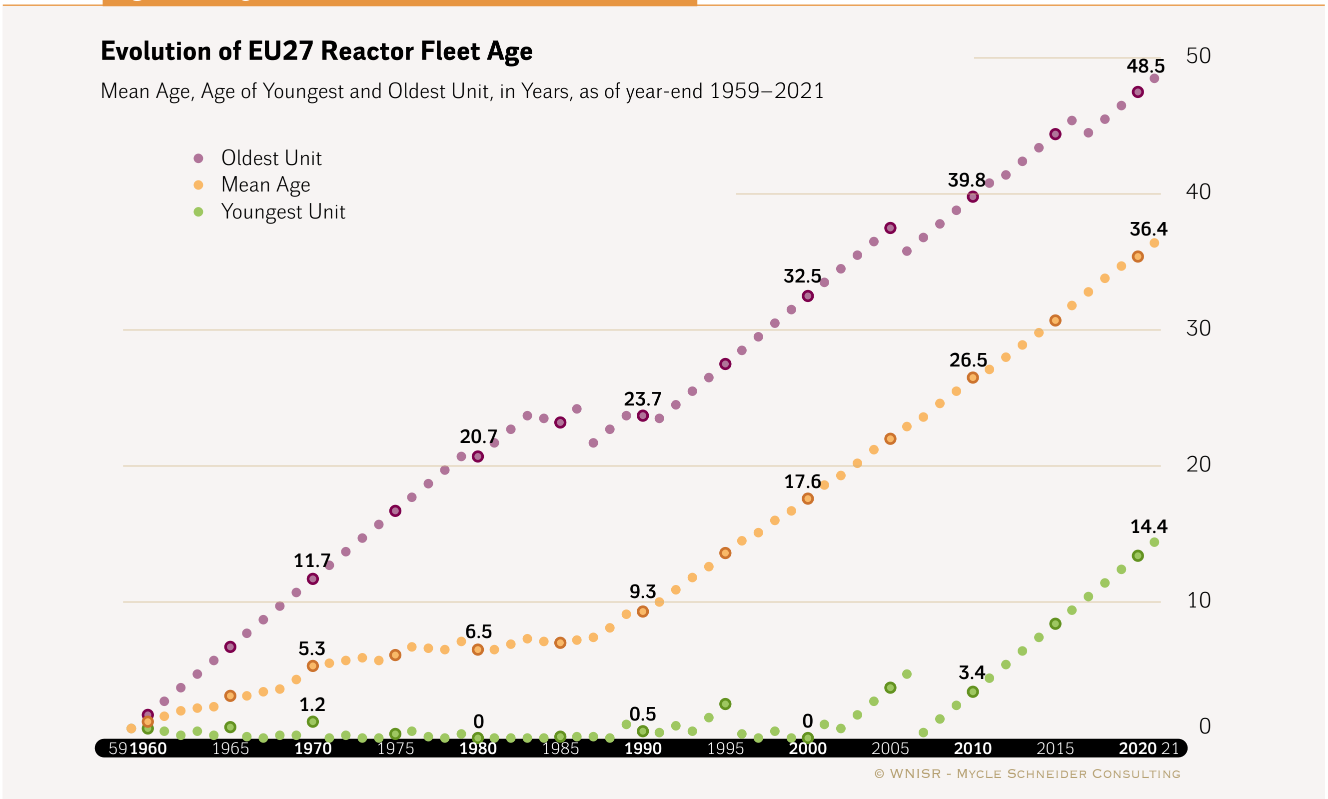
1299 - BP, "Statistical Review of World Energy – Statistical Workbook", July 2022, op. cit.

Figure 66 · Construction Starts of Nuclear Reactors in the EU27



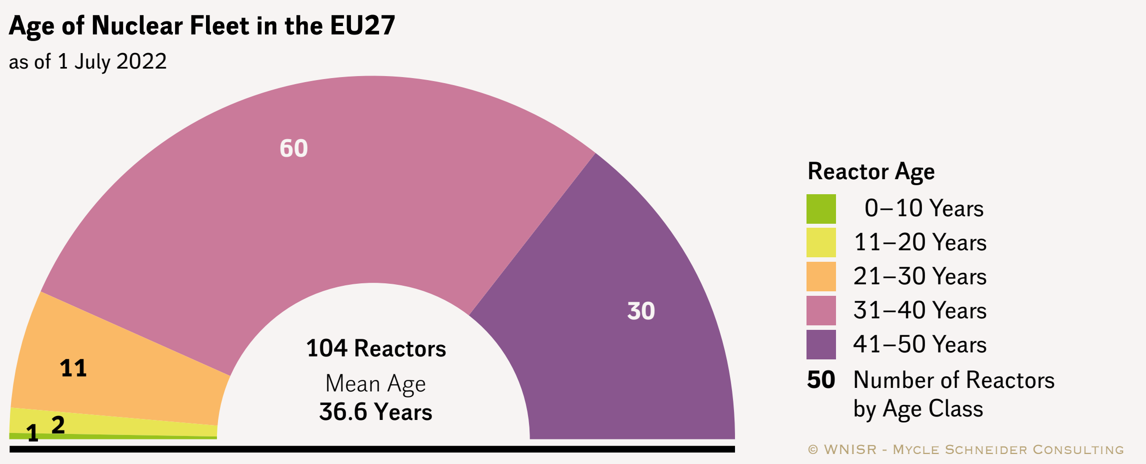
Sources: WNISR, with IAEA-PRIS, 2022

Figure 67 · Age Evolution of EU27 Reactor Fleet, 1959–2021



Sources: WNISR, with IAEA-PRIS, 2022

Figure 68 · Age Distribution of the EU27 Reactor Fleet



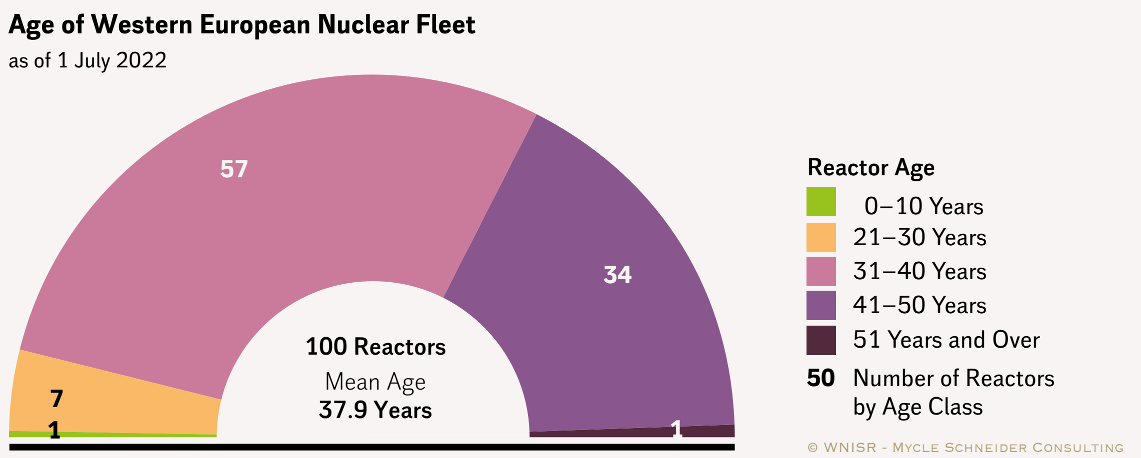
Sources: WNISR, with IAEA-PRIS, 2022

WESTERN EUROPE

As of mid-2022, 100 nuclear power reactors operated in Western Europe (including U.K. and Switzerland), 60 units fewer than in the peak years 1988–89. Two reactors were closed in the U.K. (Hunterston B-1 in November 2021 and Hunterston B-2 in January 2022). Three reactors were closed in the EU27, Brokdorf, Grohnde and Gundremmingen-C in Germany in the second half-year of 2021. One reactor was connected to the grid in Finland.

With Switzerland operating two reactors for over 50 years—Beznau-1 (53), Beznau-2 (close to 51)—the average age of operating reactors in Western Europe reaches 37.9 years (see Figure 69).

Figure 69 · Age Distribution of the Western European Reactor Fleet (incl. Switzerland and the U.K.)

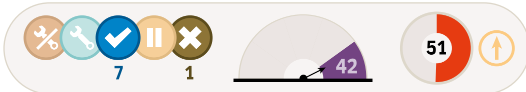


Sources: WNISR, with IAEA-PRIS, 2022

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 (EPRs) 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



After a decade of ups and downs due to multiple technical issues, nuclear reactors generated a record 48 TWh in 2021, up from 32.8 TWh in 2020 and above the previous maximum of 46.7 TWh reached in 1999.

Belgium operates seven pressurized water reactors (PWRs) that contributed 51 percent of Belgium's electricity in 2021, an 11.7 percentage point jump over 2020, and the first time since 2013 that nuclear contributes over half of the country's power. The historic maximum nuclear share was 67.2 percent in 1986. The average age of the Belgian fleet is 42.3 years.

Belgium remains highly dependent on fossil fuels as contributions to primary and final energy consumption in 2021 were 37.1 percent (45.9 percent of final energy) of oil, 26.5 percent (27.6 percent) of natural gas and 21.3 percent (8.8 percent) nuclear, with renewables at only 10 percent (6.2 percent).[1300]

The gas price increase in the fall of 2021 and the war in Ukraine have reopened the debate about the potential lifetime extension of the two most recent units, Tihange-3 and Doel-4. However, as of mid-August 2022, a final decision remains uncertain. At this point, there is no debate anymore about potential lifetime extensions of five of the seven Belgian reactors according to the time schedule specified by law.

Legally the country remains bound to a nuclear phaseout 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 be closed progressively between 2015 and 2025 (see Table 12). Practically, however, after lifetime extension to 50 years was granted for three reactors, five of the seven reactors would go offline in the single year of 2025. This represents an increasingly challenging policy goal.

1300 - SPF Economie, "Energy Key Data —Édition juillet 2022", SPF Economie, P.M.E., Classes Moyennes et Energie, Updated 20 July 2022 (in French), see https://economie.fgov.be/fr/file/5175669, accessed 21 August 2022.

Table 12 – Belgian Nuclear Fleet (as of 1 July 2022)

Reactor	Net Capacity (MW)	Grid Connection	Operating Age (as of 1 July 2021)	End of License (Latest Closure Date)
Doel-1	433	28/08/1974	47.8	10-year lifetime extension to 15 February 2025
Doel-2	433	21/08/1975	46.9	10-year lifetime extension to 1 December 2025
Doel-3	1 006	23/06/1982	40.0	1 October 2022
Doel-4	1 038	08/04/1985	37.2	1 July 2025
Tihange-1	962	07/03/1975	47.3	10-year lifetime extension to 1 October 2025
Tihange-2	1 008	13/10/1982	39.7	1 February 2023
Tihange-3	1 038	15/06/1985	37.0	1 September 2025

Sources: Belgian Law of 28 June 2015; Electrabel/GDF-Suez, 2015[1301]

Lifetime Extension of Tihange-3 and Doel-4?

Operator Electrabel, subsidiary of French group Engie, had signaled in previous years that it was interested in extending the lifetime of two or three units beyond 2025 and warned that it would need legislation to be adapted by the end of the year 2020.[1302] 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".[1303]

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".[1304] In another statement Engie explained that any lifetime extension of Tihange-2 was "not feasible" 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 (...)".[1305]

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

1301 - *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.

1302 - 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.

1303 - 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.

1304 - *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.

1305 - *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.

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".[1306]

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.[1307] In fact, Engie plans to take Doel-3 off the grid even one week early, in the night of 23 to 24 September 2022.[1308]

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 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 at 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.[1309] A final agreement is to be negotiated by the end of the year.

As these developments took place under a potentially short period of rising gas prices, malfunctioning French nuclear fleet, and the war in Ukraine, the outcome of the negotiations will be highly dependent on the energy markets and the geopolitical situation towards the end of the year.

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 fracture-toughness test results was given, on 17 November 2015, the Federal Agency for Nuclear Control (FANC) authorized the restart of Doel-3 and Tihange-2 (see previous WNISR editions for details).

1306 - 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.

1307 - Christine Scharff and Maxime Vande Weyer, "Tinne Van der Straeten, ministre fédérale de l'Énergie: "Nous sommes en situation de guerre"", Interview with Tinne Van der Straeten, Belgian Minister of Energy, *L'Echo* (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.

1308 - *RTBF*, "Sortie du nucléaire : Doel 3 sera déconnecté dans la nuit du 23 au 24 septembre", 14 July 2022 (in French), see https://www.rtbf.be/article/sortie-du-nucleaire-doel-3-sera-deconnecte-dans-la-nuit-du-23-au-24-septembre-11030952, accessed 21 August 2022.

1309 - *RTBF*, "Accord de principe entre le gouvernement fédéral et Engie en vue de prolonger l'exploitation des réacteurs nucléaires Doel 4 et Tihange 3", (in French) 22 July 2022, 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.

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.[1310]

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 binding public enquiry. In 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. [1311]

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.[1312]

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 though 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. That maintenance may only last for the amount of time strictly necessary in order to remedy that illegality.[1313]

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.[1314]

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

1310 - AFCN/FANC, "Exploitation à long terme (LTO) des centrales nucléaires belges - 2015", 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.

1311 - 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", Court of Justice of the European Union, Press Release No 100/19, 29 July 2020, see https://curia.europa.eu/jcms/upload/docs/application/pdf/2019-07/cp190100en.pdf, accessed 30 August 2022.

1312 - Ibidem.

1313 - Ibidem.

1314 - Constitutional Court, "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" , Cour Constitutionnelle, Press Release (in French), 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 Court 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.

European governments inviting them to comment on the "project" (that is the well engaged lifetime extension of Doel-1 and -2).[1315]

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 will be 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.[1316]

In its assessment of the PNEC, the European Commission notes:

> On energy security, Belgium has largely addressed the recommendation to specify the measures supporting the energy security objectives. In particular, the final plan better outlines the reform of the electricity market linked to the phase-out of the nuclear fleet. It also indicates that Belgium will implement the reforms in its market reform plan under the Electricity Regulation in a timely manner. (...) To replace 6 GW of nuclear capacity, the energy production mix is expected to make use of flexible capacity, storage and renewable energy sources.

However, the Commission also stated: "An increase in the country's energy dependence is expected after this phase-out."[1317]

Part of the nuclear phase-out strategy was the buildup of offshore wind capacities. In mid-2021, Belgium reached 2.3 GW installed capacity, around the same level as precursor-country Denmark.[1318] 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.[1319]

In 2021, offshore wind farms generated 6.9 TWh (gross) compared to 5 TWh (gross) for onshore turbines. Cumulated installed generating capacity of wind and solar reached 10.5 GW or just

1315 - Marie-Christine Marghem, Letter dated 13 August 2020, Ministry of Energy, Environment and Sustainable Development, Belgium.

1316 - 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.

1317 - European Commission, "Assessment of the final national energy and climate plan of Belgium", Commission Staff Working Document, SWD(2020) 900 final, 14 October 2020, see https://ec.europa.eu/energy/sites/ener/files/documents/staff_working_document_assessment_necp_belgium.pdf, accessed 30 August 2022.

1318 - 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.

1319 - SPF Economie, "Energy Key Data—Édition Juillet 2022", op. cit.

over 40 percent of total capacity. All renewable energies combined generated 22.9 TWh (gross) or 22.8 percent, slightly more than natural gas plants with 22.6 TWh (gross) or 22.5 percent.[1320]

Finland

See Focus Countries – Finland Focus.

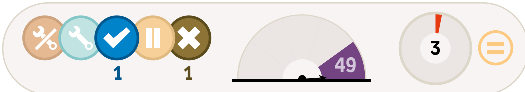
France

See Focus Countries – France Focus.

Germany

See Focus Countries – Germany Focus.

Netherlands



The Netherlands operates a single, 49-year-old 482 MW PWR at Borssele that provided 3.6 TWh in 2021 (3.9 TWh in 2020, and a maximum of 4.0 TWh in 2009), corresponding to 3.1 percent of the country's electricity, half the historic maximum of 6.2 percent back in 1986, when the country still 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.[1321] (See Decommissioning Status Report 2022).

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.[1322]

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."[1323] In its "Integrated

1320 - Ibidem.

1321 - IAEA, "Country Nuclear Power Profiles—The Netherlands", Updated 2021, see https://cnpp.iaea.org/countryprofiles/Netherlands/Netherlands.htm, accessed 10 August 2022.

1322 - 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.

1323 - 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.

National Energy and Climate Plan 2021-2030" submitted 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."[1324] 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 2021, renewables produced 40.1 TWh or about one third of all electricity generation, compared to 33 TWh in 2020 and 12.3 TWh in 2011.[1325]

In recent years, the Dutch Government drew closer attention to the possibility of continuing nuclear production beyond 2033, when the country's only existing nuclear power plant is 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. The study concluded that nuclear "could play an important role in the future energy mix of the Netherlands" and argued—in contradiction with all major international assessments (see Nuclear Power vs. Renewable Energy Deployment)—that both large units and SMRs would be "cheaper" than renewable technologies.

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*).[1326]

Dutch nuclear operator Elektriciteits Produktiemaatschappij Zuid-Nederland (EPZ), co-owned by Provinciale Zeeuwsche Electriciteits-Maatschappij or PZEM (70 percent)—former Delta—and German utility RWE (30 percent) via Energy Resources Holding (ERH),[1327] 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. Alternatively, 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, or at least 1,500 MW capacity. This would correspond to current newbuild projects of European Pressurized Water Reactors (EPR)

1324 - 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.

1325 - Gross Generation, from BP, "bo Statistical Review of World Energy 2022—71st Edition", June 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 10 August 2022.

1326 - *NEI*, "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.

1327 - 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, p. 22, see https://zoek.officielebekendmakingen.nl/blg-894160.pdf, accessed 10 August 2022.

or Advanced Pressurized Water Reactors (APR), "safe and reliable" technologies according to EPZ.

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.[1328] A lifetime extension of 10 to 20 years would result in nuclear operation at Borssele of at least 70 years and require amendments to the "Borssele Convenant" and the Nuclear Energy Act, as the current legislation prohibits the regulator to even consider an application for prolonged operation at Borssele.[1329] In 2020, the Dutch Parliament decided to inquire into the legislative changes required to allow a lifetime extension.[1330]

"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 priva te investors, and has too long a horizon."

In terms of nuclear newbuild, various plans had been made to attempt the construction of a new plant (see previous WNISR editions). The plant was to deliver up to 2,500 MW capacity, but has made no progress since 2012, when Delta—then majority shareholder—put plans on ice "for at least two years" citing unfavorable investment conditions and low energy prices.[1331]

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 nuclear power plants to achieve the envisioned CO_2 reduction goals of -70 percent by 2035 and -80 percent by 2040. A total of €5 billion (US$$_{2021}$5.6 billion) is planned to be spent by the Dutch government until 2030 to facilitate the construction of the new plants. However, the current legislative period ends in 2025, until when €500 million (US$$_{2021}$564 million) are to be spent for nuclear development.[1332]

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." 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)

1328 - EPZ, "Visie EPS op kernenergie in Nederland na 2033" ["EPZ's Vision on Nuclear Energy in the Netherlands post-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.

1329 - 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, accessed 1 August 2022.

1330 - IAEA, "Country Nuclear Power Profiles—The Netherlands", 2021, op. cit.

1331 - *SPIEGEL ONLINE*, "Bau des Atomkraftwerks in Borssele verschoben" ["Construction of the Nuclear Power Plant in Borssele postponed"], 24 January 2012, see https://www.spiegel.de/wissenschaft/technik/niederlande-bau-des-atomkraftwerks-in-borssele-verschoben-a-811010.html, accessed 12 July 2022; *Uranium Intelligence Weekly*, "Netherlands", 23 January 2012.

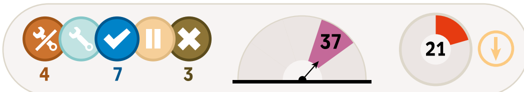
1332 - VVD, D66, CDA and ChristenUnie, "Omzien naar elkaar, vooruitkijken naar de toekomst - Coalitieakkoord 2021-2025" ["Coalition Agreement 2021–2025"], People's Party for Freedom and Democracy, Democrats 66, Christian Democratic Appeal and the Christian Union, 15 December 2021, see https://www.parlement.com/9291000/d/pdfs/coalitieakkoord-2021-2025.pdf, accessed 12 July 2022.

cost risks in comparison to implementing a completely new reactor design.[1333] 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 is expected that a choice will only be possible by 2023.

The KPMG report considers SMRs an "interesting option" to market parties but suggests waiting until "any FOAK problem is over" to identify successful projects, deeming the start of such a process impossible before 2027–2033. As a result of the consultation, outgoing State Secretary for Economic Affairs and Climate Policy, Dilan Yesilgöz-Zegerius commissioned a further study into the potential inclusion of nuclear power in the country's energy and climate goals.[1334]

The Netherlands has a long tradition of nuclear research and development going back to the early 1930s.[1335] The most recent development in this sector is the submission of a nuclear permit application for the new medical isotope production and research reactor Pallas at Petten, Noord-Holland, in June 2022. Pallas is to replace the ageing High Flux Reactor that has been operating since 1960. Operation of the new 55 MWth reactor is to begin around 2026, pending a final decision by the Dutch government.[1336]

Spain



As of July 2022, Spain operates seven reactors that provided 54.2 TWh in 2021, compared to 55.8 TWh in 2020, representing 20.8 percent of the country's electricity generation, compared to 22.2 percent in 2020 and a maximum of 38.4 percent in 1989. Spain's reactors have a mean operating age of 37.4 years as of mid-2022. Since WNISR2021, the application for license extension for both reactors at the Asco plant was approved, allowing to stretch operational lifetimes of both reactors up to 2030 and 2031, respectively. This remains however in line with Spain's nuclear phaseout protocol.

Spanish nuclear ownership is concentrated mainly with utilities Iberdrola and Endesa. Both utilities have shared ownership with Naturgy at Almaraz-1 and -2, and with Naturgy and EDP at Trillo. Endesa is the sole owner of Asco-1, and Iberdrola fully owns Cofrentes. At the two other plants, Asco-2 and Vandellos-2, they have a shared ownership structure.[1337]

1333 - 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.

1334 - 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.

1335 - WNA, "Nuclear Power in the Netherlands", April 2022, op. cit.

1336 - Stichting Voorbereiding Pallas-reactor, "PALLAS Schedule", Pallas Reactor, 2022, see https://www.pallasreactor.com/en/pallas-activities/realisation-reactor/schedule/, accessed 17 August 2022.

1337 - Foro Nuclear, "Nuclear power in Spain", Undated, see https://www.foronuclear.org/en/nuclear-power/nuclear-power-in-spain/, accessed 11 July 2022.

In January 2019, Spain's coalition government agreed on a nuclear phaseout plan with utilities Endesa, Iberdrola and Naturgy which was part of the overall Integrated National Energy and Climate Plan (INECP).[1338] All of Spain's reactors are expected to be closed by 2035; however, the policy also secured the possibility to apply for lifetime extensions beyond 40 years for all reactors, in contrast to previous governing Socialist Party (PSOE) policy.[1339]

The current INECP (2021-2030) was published in 2020.[1340] The 2030 target of 161 GW of total installed power generating capacity is to include 50 GW of wind, 39 GW of solar PV, 27 GW of CCGTs (Combined Cycle Gas Turbines), 16 GW hydro, 9.5 GW pumped hydro, 7 GW thermo-solar, and 3 GW nuclear (1.9 percent), compared to the installed 7 GW nuclear as of mid-2022. Although the exact relative shares may vary, the plan envisions that by then renewables will provide 74 percent of generated electricity, and 42 percent of final energy.[1341] The country's 2050 objectives stipulate renewables to deliver an ambitious 100 percent of electricity production and 97 percent of total energy.[1342]

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.[1343] The agreement is based on the condition that no more than €600 million (US$$_{2019}$677 million) will have to be spent on the units during their remaining operational life.[1344] 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.[1345] The decision extended permission for Almaraz-1 and -2, respectively 41 and 39 years old, to operate until 1 November 2027 and 31 October 2028. The CSN approval sets various safety and compliance

1338 - Carmen Monforte, "El Gobierno cierra el calendario con las fechas de clausura de cada central nuclear" ["The government finalizes the timeline of decommissioning dates for each nuclear power plant"], *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.

1339 - *Público*, "La ministra Ribera afirma que es necesario prolongar la vida de las centrales nucleares" ["Minister Ribera affirms it is necessary to extend operation of nuclear power plants"], 3 March 2019 (in Spanish), see https://www.publico.es/politica/energia-nuclear-prolonga-vida-centrales-nucleares.html, accessed 8 July 2021.

1340 - *Renewables Now*, "Spain raises ambitions in new 2030 NECP - more emission cuts, wind, solar", 13 April 2020, see https://renewablesnow.com/news/spain-raises-ambitions-in-new-2030-necp-more-emission-cuts-wind-solar-694786/, accessed 8 July 2021.

1341 - European Commission, "Integrated National Energy and Climate Plan 2021-2030 - Spain", January 2020, see https://energy.ec.europa.eu/system/files/2020-06/es_final_necp_main_en_0.pdf, accessed 11 July 2022.

1342 - 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", May 2021, see https://iea.blob.core.windows.net/assets/2f405ae0-4617-4e16-884c-7956d1945f64/Spain2021.pdf, accessed 16 August 2022.

1343 - Iberdrola, "Iberdrola finalises the Almaraz renewal agreement, which guarantees economic activity and employment at the plant for the next 25 years", 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.

1344 - 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.

1345 - MITECO, "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" ["Decree TED-773-2020, of 23 July granting the renewal of operating license of Alamrez Nuclear Power Plant, Units I and II "], Ministerio para la Transición Ecológica y el Reto Demográfico, 6 August 2020 (in Spanish), 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 ; and *NEI Magazine*, "Spain Extends NPP Operation for the Last Time", 31 July 2020, see https://www.neimagazine.com/news/newsspain-extends-npp-operation-for-the-last-time-8055759/, accessed 15 August 2022.

conditions, including the requirement, as noted above, to invest up to €600 million.[1346] The license of the units had already been extended by 10 years in 2010.[1347]

The Almaraz plant is located adjacent to the Tagus River in an area of significant seismic activity and 110 kilometers from the Portuguese border, resulting over the years in strong opposition on the Portuguese side.[1348] 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).[1349] 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,[1350] and filed a complaint with the United Nations Economic Commission for Europe (UNECE) in October 2020.[1351] As of August 2022, the case is still pending, but in its response dated 6 September 2021, the UN stated that neither EU nor Spanish regulations would impose an EIA for a lifetime extension and refuted the notion that a definitive period was defined under the "design life" or "useful life",[1352] thus leaning towards the dismissal of the alleged failure to comply with protocol. The position is quite surprising, as the European Court of Justice has nullified lifetime extensions in Belgium in the past, precisely on the grounds of a missing EIA with transborder consultation (see section on Belgium in Annex 1).

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.[1353] Under the current

1346 - *elEleconomista*, "El CSN autoriza a la central nuclear de Almaraz a operar hasta octubre de 2028" ["CSN Authorizes the Almaraz Nuclear Power Plant to Operate Until October 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; *NEI*, "Life extension approve for Spain's Almaraz nuclear plant", 15 May 2020, see https://www.neimagazine.com/news/newslife-extension-approve-for-spains-almaraz-nuclear-plant-7931673, accessed 15 August 2022.

1347 - *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.

1348 - *Portugal Resident,* "Urgent meeting demanded with Spain over obsolete Almaraz nuclear plant", 29 September 2016, see https://www.portugalresident.com/urgent-meeting-demanded-with-spain-over-obsolete-almaraz-nuclear-plant/; and Andrei Khalip,"Portugal to complain to EU over Spain's planned nuclear dump site", *Reuters*, 12 January 2017, see https://www.reuters.com/article/portugal-nuclearpower-spain-idINKBN14W2HG, *TPN/LUSA*, "Portugal Parliament votes to request closure of Spain's Almaraz nuclear plant", as published in *The Portugal News*, 25 May 2017, see https://www.theportugalnews.com/news/portugal-parliament-votes-to-request-closure-of-spains-almaraz-nuclear-plant/42052, all accessed 18 August 2022.

1349 - *LUSA*, "Governo quer que extensão de funcionamento de Almaraz seja avaliada" ["Government wants Almaraz operating extension reviewed"], 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

1350 - *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.

1351 - 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.

1352 - UNECE, "ACCC/C/2020/183 Spain", Undated, see https://unece.org/env/pp/cc/accc.c.2020.183_spain; UNECE, "Report on the complaint made by the Portuguese political party PAN with regard to the implementation of the Aarhus Convention to the renewal of the operating permit of Almaraz Nuclear Power Plant, Units I and II", 6 September 2021, see https://unece.org/sites/default/files/2021-09/frPartyC183_06.09.2021.pdf; both accessed 16 August 2022.

1353 - *Platts Nuclear News Flashes*, "Operator of Spain's Vandellos-2 applies for 10-year license renewal", 28 March 2019.

NCP, 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.[1354]

The Cofrentes reactor, Spain's last operational commercial BWR, was granted a license extension to 30 November 2030 in 2021.[1355]

CSN announced on 8 July 2021 that it had begun the analysis for license renewal of the two PWRs at Ascó for nine and ten years respectively.[1356] 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 October 2021, allowing for the operation of Unit 1 to 2030 and Unit 2 to 2031.[1357] .

The only reactor to not yet having applied for license renewal is Trillo. This plant is currently operating under a license valid until November 2024 and is scheduled to close in 2035.[1358]

The adoption in September 2021 of a law to limit electricity bills for consumers triggered the ire of Foro Nuclear (the Spanish Nuclear Industry lobby group). It called for nuclear energy to be exempt from the legislation as it would lead "to the cessation of the activity of the entire nuclear fleet" and claimed that operators would not have requested lifetime extensions had the bill been in effect at the time of application.[1359]

Over the years, Foro Nuclear has been very vocal about Spain's fiscal framework and the industry's financial difficulties. In February 2021, Foro Nuclear's Chairman indicated that for the first time the fleet was operating with a negative operating cash flow.[1360] In June 2021, the draft bill to cap energy prices for consumers sparked concern and fierce criticism from the organization stating that "the draft law, the current taxes and levies and the future market context increase the financial suffocation of the nuclear fleet and drive it to the cessation of its activity."[1361]

1354 - CSN, "El Pleno del CSN informa favorablemente la solicitud de renovación de autorización de explotación de la central nuclear Vandellós II (Tarragona)" ["The Plenary Session of the CSN reports favorably on the request for the renewal of the operating authorization for the Vandellós II Nuclear Power Plant (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.

1355 - *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 8 July 2021.

1356 - CSN, "El CSN inicia el análisis de la solicitud de renovación de autorización de explotación de la central nuclear Ascó" ["CSN begins the review of the application for renewal of the operating authorization of the Ascó nuclear power plant"], 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.

1357 - 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.

1358 - CNAT, "2021 CNAT Informe Ambiental", Centrales Nuclears Alamaraz-Trillo, March 2022, see https://www.cnat.es/publipdf/Informe_Ambiental_2021_esp.pdf, accessed 11 July 2022.

1359 - Foro Nuclear, "Nuclear power plants are not amortized and nuclear generation is currently incurring losses", Press Release, 3 June 2021, see https://www.foronuclear.org/en/press-room/press-releases/nuclear-power-plants-are-not-amortized-and-nuclear-generation-is-currently-incurring-losses/; and *NEI Magazine*, "Spain's economic support measures cause concern to nuclear industry", 21 September 2021, see https://www.neimagazine.com/news/newsspains-economic-support-measures-cause-concern-to-nuclear-industry-9095609/, both accessed 16 August 2022.

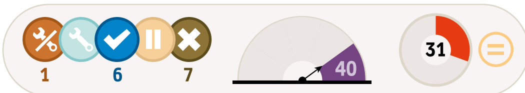
1360 - David Dalton, "'Nuclear Is Being Penalised' / Head Of Spanish Industry Group Says Funding Is More Complicated", *NucNet*, 25 February 2021, see https://www.nucnet.org/news/head-of-spanish-industry-group-says-funding-is-more-complicated-2-4-2021, accessed 18 August 2022.

1361 - Foro Nuclear, "Nuclear power plants are not amortized and nuclear generation is currently incurring losses", Press Release, 3 June 2021, op.cit.

In September 2021, Foro Nuclear complained that the plants were not amortized yet, with over €5.5 billion ($\text{US}\$_{2021}$6.7 billion) in fixed tied-up capital pending amortization, of which €3 billion ($\text{US}\$_{2021}$3.7 billion) invested over the past ten years, and costs of about €300 million ($\text{US}\$_{2021}$366 million) in yearly spending, which would amount to €3 billion ($\text{US}\$_{2021}$3.7 billion) to be spent to "maintain optimal safety and reliability conditions" until the plants close.[1362] Based on Endesa calculations, as reported in May 2021, generation costs were well over €50/MWh ($\text{US}\$_{2021}$60.4/MWh), with 40 percent allocated as tax and fees for radioactive waste management.[1363] Foro Nuclear also stated that contributions to Enresa for radioactive waste management and future decommissioning had increased from €6.69/MWh to €7.98/MWh ($\text{US}\$_{2021}$8.1–9.6/MWh),[1364] (see Decommissioning Status Report 2022).

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) formally denied approval for a construction application of a uranium processing plant in late 2021. At the time Berkeley Energia said it was considering legal action against the decision.[1365] No updates on the matter have been released since.

Sweden



Sweden's nuclear fleet of six reactors generated 51.43 TWh in 2021, an 8.6 percent increase over the previous year. In 2021, 30.8 percent of the country's electricity production came from nuclear power plants. Nuclear electricity production peaked in 1996 at 52.4 percent.

For more than four decades, phase-out 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 phase-out 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 this decision, new reactors could be built, but only at pre-existing sites.[1366] Since then, the goal of carbon-neutrality has been pulled forward to 2045,[1367] with the goal of a 100 percent

1362 - Foro Nuclear, "Nuclear power plants are not amortized and nuclear generation is currently incurring losses", 3 June 2021, op. cit.

1363 - David Dalton, "IEA Says Madrid Should Not Rule Out Long-Term Use Of Nuclear Technology", *NucNet*, 26 May 2022, see https://www.nucnet.org/news/iea-says-madrid-should-not-rule-out-long-term-use-of-nuclear-technology-5-3-2021, accessed 18 August 2022.

1364 - David Dalton, "Foro Nuclear President Renews Call For Reduction In 'Suffocating' Fiscal Pressure", *NucNet*, 21 May 2021, see https://www.nucnet.org/news/foro-nuclear-president-renews-call-for-reduction-in-suffocating-fiscal-pressure-5-5-2021, both accessed 18 August 2022.

1365 - *WNN*, "Spanish uranium project denied authorisation", 29 November 2021, see https://www.world-nuclear-news.org/Articles/Spanish-uranium-project-denied-authorisation, accessed 12 July 2022.

1366 - WNA, "Nuclear Power in Sweden", World Nuclear Association, June 2022, see https://world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx, accessed 12 July 2022.

1367 - Ministry of the Environment and Energy, "Sweden's Climate Policy Framework", Government Offices of Sweden, 11 March 2021, see https://www.government.se/articles/2021/03/swedens-climate-policy-framework/, accessed 31 August 2022.

"renewable" electricity system by 2040, explicitly stressing that this does not automatically correspond to a nuclear phaseout.[1368]

Despite the postponement of the nuclear phaseout, several reactors have closed due to economic reasons. In 2015, operators decided to close the country's four oldest reactors.[1369] 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 a year later, in 2020. First grid connection for all these units occurred in 1974, to the exception of Oskarshamn-1, which was first connected to the grid in 1971. 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 as late as 2045.[1370]

To operate reactors into the 2040s, owners need to win approval following ten-year periodic safety reviews. The first to do so under the new 2016-policy were the 39-year-old Forsmark-1 and 38-year-old Forsmark-2, which secured approval on 18 June 2019 from the Swedish Radiation Safety Authority (SSM) to operate for 10 more years until 2028.[1371] 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."[1372]

This could mean significant refurbishment work may be indispensable in the coming years.

Major construction work at all of Sweden's reactors—with significant impact on production—was completed during 2020. This relates to the requirement that all reactors operating beyond 2020 have Independent Core Cooling Systems (ICCS) in place.[1373] The new system is a consequence of the stress tests following the Fukushima accidents and the SSM requirements

1368 - The Ministry of Infrastructure, "Sweden's Integrated National Energy and Climate Plan", Government of Sweden, 16 January 2020, see https://energy.ec.europa.eu/system/files/2020-03/se_final_necp_main_en_0.pdf, accessed 31 August 2022.

1369 - OKG, "Decision Made Regarding Premature Shutdown of Units Oskarshamn 1 and Oskarshamn 2", Press Release, 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.

1370 - SKB, "Plan 2019—Costs from and including 2021 for the radioactive residual products from nuclear power", Svensk Kärnbränslehantering, Swedish Nuclear Fuel and Waste Management Co, 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, 5 January 2021, see https://group.vattenfall.com/press-and-media/newsroom/2021/the-ringhals-1-reactor-has-crossed-the-finish-line; also Vattenfall, "Ringhals 2 nuclear plant shuts down", Press Release, see https://group.vattenfall.com/press-and-media/newsroom/2019/ringhals-2-nuclear-plant-shuts-down, all accessed 31 August 2022.

1371 - SSM, "Forsmark har förutsättningar att fortsätta driva F1 och F2 strålsäkert till 2028s", Strålsäkerhetsmyndigheten, Swedish Radiation Safety Authority, 24 June 2019 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/press/nyheter/2019/forsmark-har-forutsattningar-att-fortsatta-driva-f1-och-f2- stralsakert-till-2028/, accessed 25 June 2019.

1372 - SSM, "Återkommande helhetsbedömning—Forsmarks Kraftgrupp AB—Forsmark 1 och 2" ["Periodic General Assessment—Forsmarks Kratgrupp AB—Forsmark 1 and 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 24 June 2019.

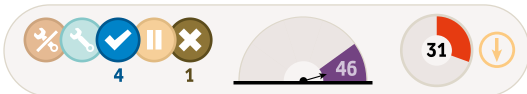
1373 - Ministry of the Environment, "Sweden's Eighth National Report under the Convention on Nuclear Safety—Sweden's Implementation of the Obligations of the Convention", Swedish Government, Ds 2019:16, August 2019 see https://www.regeringen.se/4adae6/contentassets/c8c431c94efb4c4abefb38ca36272b5a/swedens-eighth-national-report-under-the-convention-on-nuclear-safety-ds-201916.pdf, accessed 16 June 2020.

for an independent core cooling system designed to withstand extreme external hazards. On 18 December 2020, SSM confirmed that the reactors at Forsmark, Ringhals and Oskarshamn essentially meet the set conditions and requirements.[1374]

The historical nuclear phaseout plans and the current limitation of potential newbuild to existing sites, in effect means the replacement of obsolete units, while the Swedish strategy has focused on capacity upgrades at existing reactors.[1375] For example, at Forsmark, this has been ongoing since the 1980s, with the most recent plans to extend Unit 1 by an additional 100 MW, having been announced in mid-2022.[1376] In total, as of mid-2022, this strategy has led to over 1 GW of additional nuclear capacity in existing power plants.

At Ringhals and Oskarshamn decommissioning work is underway. However, at both sites, the operators are envisaging new nuclear reactors. These strategies are focusing on SMR technology. Public utility Vattenfall, after having entered into a cooperation agreement with Estonian nuclear start-up Fermi Energia in 2021, has begun work on a pilot study to be completed by early 2024 on the introduction of at least two SMRs at Ringhals.[1377] It is unclear what reactor design and when it would be commercially available, although CEO of Vattenfall, Anna Borg indicated that "it should be possible to have the first SMR reactor in operation by the early 2030s." Additionally, in February 2022, a SEK99 million (US$10.6 million) grant was awarded by the Swedish Energy Agency to a joint venture of Uniper and LeadCold to design and construct a prototype lead cooled SMR at the Oskarshamn site. LeadCold is a spin-off from KTH Royal Institute of Technology that works on design and safety issues for lead-cooled reactor systems. At present, the goal is a commercialization in the 2030s.[1378] Another Swedish company, Kärnfull Next, cooperates with GE Hitachi on a project to build a BWRX-300 SMR in Canada.[1379]

Switzerland



After a 9 percent drop in 2020, Swiss nuclear output declined again by 19.4 percent from 23 TWh in 2020 to 18.5 TWh in 2021. Total national electricity generation dropped in the first COVID-19 year by 3.4 percent and in 2021 by another 8.2 percent, nuclear still generated

1374 - SSM, "Forsmark, Ringhals och OKG uppfyller kraven på oberoende härdkylning" ["Forsmark, Ringhals and OKG meet the requirements for independent core cooling"], Press Release (in Swedish), 18 December 2020, see https://www.stralsakerhetsmyndigheten.se/press/nyheter/2020/forsmark-ringhals-och-okg-uppfyller-kraven-pa-oberoende-hardkylning/, accessed 15 July 2021.

1375 - WNA, "Nuclear Power in Sweden", World Nuclear Association, June 2022, see https://world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx, accessed 12 July 2022.

1376 - 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, accessed 12 July 2022; 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 14 July 2022.

1377 - *WNN*, "Vattenfall considers building SMRs at Ringhals", *World Nuclear News*, 28 June 2022, see https://www.world-nuclear-news.org/Articles/Vattenfall-considers-building-SMRs-at-Ringhals, accessed 12 July 2022.

1378 - *WNN*, "Funding for demonstration Swedish SMR", *World Nuclear News*, 15 February 2022, see https://www.world-nuclear-news.org/Articles/Funding-for-demonstration-Swedish-SMR, accessed 12 July 2022.

1379 - *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 12 July 2022.

35.1 percent of the country's electricity in 2020 while the share dropped to 30.8 percent in 2021.[1380]

One of the reasons for the low nuclear output in 2021 was a six-month outage of the Leibstadt reactor for condenser replacement and other backfitting work. The outage lasted one month longer than anticipated.[1381]

With an average age of 46.3 years (see Figure 70), Switzerland operates the second oldest nuclear fleet and—with Beznau-1, age 53—the oldest commercially operating reactor in the world. Beznau-2 is almost 51 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 report that some improvements would be needed in the "assessment and maintenance of the quality" of the spent fuel pools and increased ageing surveillance of certain components. ENSI has established a list of over 30 "requests" of measures to be implemented with individually specified timelines.[1382]

An independent study 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". [1383]

Another independent report on the Leibstadt plant listed numerous deficiencies of the safety standards including insufficient protection against airplane crash 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 cannot be replaced or appropriately backfitted.[1384] Leibstadt will reach its design lifetime of 40 years in May 2024.

In early July 2021, it was reported that the Federal Energy Office has engaged in talks with the operators of the remaining four reactors about the potential lifetime extension to 60 years.[1385] However, in Switzerland, there is no time limit on licenses. Nuclear reactors can operate as

1380 - SFOE/BFE, "Schweizerische Elektrizitätsstatistik 2021/Statistique Suisse de l'Électricité 2021", Swiss Federal Office of Energy, June 2022 (in German and French), see https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/elektrizitaetsstatistik.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvMTA5NDI=.html, accessed 19 August 2022. The official national figures vary slightly from the IAEA-PRIS statistics.

1381 - *WNN*, "Daily – In other News", 13 January 2022, see https://wna.informz.ca/informzdataservice/onlineversion/ind/bWFpbGluZ2luc3RhbmNlaWQ9MTMxNzE3NCZzdWJzY3JpYmVyaWQ9OTE5OTU5MzI5, accessed 20 August 2022.

1382 - ENSI/IFSN, "Sicherheitstechnische Stellungnahme zur Periodischen Sicherheitsüberprüfung 2017 des Kernkraftwerks Beznau", Eidgenössisches Nuklearsicherheitsinspektorat/Swiss Federal Nuclear Safety Inspectorate, 16 November 2021 (in German), see https://www.ensi.ch/de/dokumente/sicherheitstechnische-stellungnahme-zur-periodischen-sicherheitsueberpruefung-2017-des-kernkraftwerks-beznau/, accessed 20 August 2022.

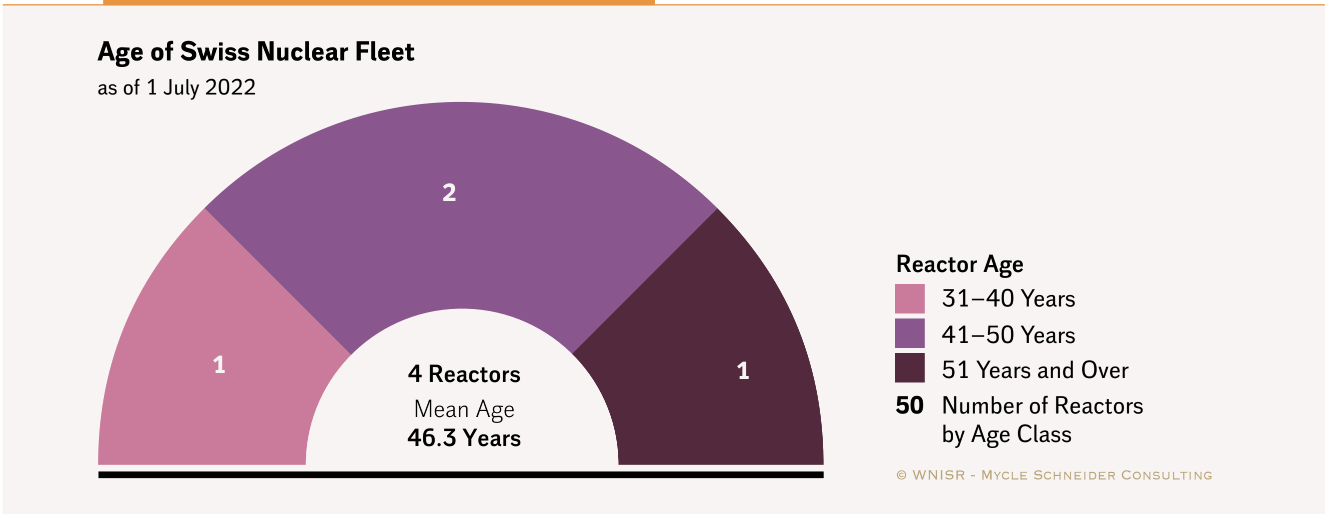
1383 - Kim Wallin, "Assessment of Fractographic Investigation Report and Applicability of the Master Curve Method", Report Kw-2022-01, commissioned by Schweizerische Energiestiftung/Swiss Energy Foundation, February 2022, see https://www.energiestiftung.ch/news/akw-beznau-1-sicherheitsnachweis-erneut-in-der-kritik, accessed 20 August 2022.

1384 - Manfred Mertins, "Studie zu den Sicherheitsdefiziten des Schweizer AKW Leibstadt (Defizit-Studie KKL)", commissioned by Schweizerische Energiestiftung/Swiss Energy Foundation, August 2021 (in German), see https://energiestiftung.ch/files/energiestiftung/publikationen/pdf/20210829_Studie%20zu%20den%20Sicherheitsdefiziten%20des%20Schweizer%20AKW%20Leibstadt_final.pdf, accessed 1 September 2022.

1385 - Michel Sutter, "Laufzeitverlängerung der Kernkraftwerke sorgt für Diskussionen", *Energate Messenger*, 5 July 2021.

long as they are deemed safe by the safety authorities. The Swiss Energy Foundation has called the lifetime extensions "an unnecessary and dangerous game to gain time".[1386]

Figure 70 · Age Distribution of the Swiss Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2022

On 21 May 2017, 58 percent of Swiss voters agreed to the Energy Strategy 2050 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 and the reprocessing of spent fuel. The "totally revised energy legislation" entered into force on 1 January 2018.[1387]

The legislation is comprehensive, providing a framework for grid development regulation, renewable energy incentives, auto-consumption, energy efficiency and the "organic phase-out" 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.[1388]

Domestic production of non-hydro renewable-energy based electricity increased by 6.3 percent in 2021 to reach a modest 5 TWh, still representing only 7.7 percent of the net power generated in the country, while hydro generated 61.5 percent of the country's electricity.[1389]

United Kingdom

See Focus Countries – United Kingdom Focus.

1386 - Ibidem.

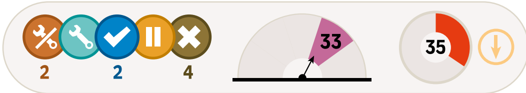
1387 - Federal Department of the Environment, Transport, Energy and Communications, "Wichtigste Neuerungen im Energierecht ab 2018", Swiss Federal Office of Energy, 2 November 2017 (in German), see https://www.newsd.admin.ch/newsd/message/attachments/50166.pdf, accessed 12 July 2018.

1388 - 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 1 September 2022.

1389 - SFOE, "Schweizerische Elektrizitätsstatistik 2020/Statistique Suisse de l'Électricité 2021", op. cit.

CENTRAL AND EASTERN EUROPE

Bulgaria



In Bulgaria, nuclear power provided 15.8 TWh or 34.6 percent of the country's electricity in 2021, down from a maximum of 47.3 percent in 2002, which is produced by two Russian designed VVER-1000 reactors at Kozloduy.

Originally, there were six reactors on site, but the oldest four (VVER-440 v230) were closed as part of an agreement by the G7 in Munich in 1992, implemented in the agreement to join the European Union in 2007.

The two VVER-1000 (V-320) reactors (Units 5 and 6), that started up in 1987 and 1991 respectively, are undergoing a relicensing program intending to try and extend their operating lifetimes for up to 60 years, compared to their initial 30-year license. In 2017, Unit 5 was awarded permission for an additional 10-year operating lifetime, 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 BGN292 million (US$$_{2019}$163 million).[1390] In December 2019, it was announced that the Russian fuel company TVEL and Kozloduy NPP had signed a five-year fuel-supply contract until 2025. This is despite previous requests from the EU for diversification of nuclear fuel supply in Bulgaria.[1391] As of July 2022, Russia had Bulgaria entirely cut off gas supply.

There have been repeated 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.[1392] In 2018, the Government started to revive the project and began searching for new investors,[1393] then in March 2019, it announced that it was preparing to select a single strategic investor for the project and had started a tender procedure, which was officially launched after publication in the *EU Official Journal* two months later. Initial interest has been expressed by Framatome, General Electric, China National Nuclear Corporation (CNNC) and Rosatom.[1394]

In December 2019, during a visit from 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. The same month, 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,

1390 - *WNN*, "Kozloduy Unit 6 Clear to Operate for Another 10 Years", 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.

1391 - *NEI Magazine*, "Russia to supply fuel to Kozloduy NPP until 2025", *Nuclear Engineering International*, 5 December 2019, see https://www.neimagazine.com/news/newsrussia-to-supply-fuel-to-kozloduy-npp-until-2025-7541032/, accessed 4 April 2021.

1392 - *WNN*, "Bulgarian Government Drops Belene", *World Nuclear News*, 29 March 2012, see https://www.world-nuclear-news.org/Articles/Bulgarian-government-drops-Belene, accessed 29 August 2022.

1393 - *WNN*, "Bulgarian parliament approves restart of Belene investor talks", *World Nuclear News*, 8 June 2018, see https://world-nuclear-news.org/Articles/Bulgarian-parliament-approves-restart-of-Belene-in, accessed 29 August 2022.

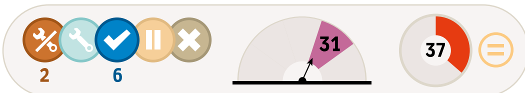
1394 - *NEI Magazine*, "Bulgaria launches call for strategic investor for Belene NPP", 24 May 2019, see https://www.neimagazine.com/news/newsbulgaria-launches-call-for-strategic-investor-for-belene-npp-7224432, accessed 29 August 2022.

although Russia very much sees the project as its own. 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.

However, despite some developments, procedures were halted due to the coronavirus pandemic, and in January 2021, the Government appeared to abandon the plans for construction of a reactor at Belene. This was reported in the English language press as "this third suspension is likely to end the Belene nuclear project forever".[1395] Nevertheless this was not officially the end of nuclear new-build, with suggestions that attention should once again be focused on building a 7th reactor at Kozloduy, which would include the movement of equipment from Belene.[1396] This was confirmed in February 2022, by Prime Minister Kiril Petkov suggesting that two new units would be built at Kozloduy. While the design of any future reactors is far from clear, NuScale has signed a preliminary agreement for SMRs at Kozloduy.[1397]

Bulgaria is heavily dependent on Russia for its energy, including 70 percent of its gas, as well as 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 is no immediate threat to Bulgaria's nuclear energy production,[1398] however, Bulgaria is seeking to diversify its source of nuclear fuel and in July 2022 the energy minister announced that from 2024 one of the two remaining Kozloduy units would switch supplier, although the company was not named.[1399] However, on 4 February 2021, the plant management signed a contract with Westinghouse Electric Sweden "for the development of safety analyses for licensing and implementing of alternative nuclear fuel on Unit 5".[1400]

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 2021, nuclear plants generated 29 TWh, compared to 28.4 TWh in 2020, representing a 36.6 percent share in electricity production. In May 2022, ČEZ announced that it had

1395 - 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.

1396 - *NEI Magazine*, "Bulgaria considers using Belene reactors to expand Kozloduy plant", *Nuclear Engineering International*, 25 January 2021, see https://www.neimagazine.com/news/newsbulgaria-considers-using-belene-reactors-to-expand-kozloduy-plant-8472288/, accessed 4 April 2021.

1397 - 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.

1398 - 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.

1399 - Lyubomir Gigov, "One Kozloduy N-Plant Unit Expected to Run on Non-Russian Fuel after 2024 - Energy Minister", *Bulgarian News Agency*, 3 July 2022, see https://www.bta.bg/en/news/economy/291490-one-kozloduy-n-plant-unit-expected-to-run-on-non-russian-fuel-after-2024-ener, accessed 8 July 2022.

1400 - Vladimir Pekic, "Bulgaria assessing safety of Westinghouse nuclear fuel for Kozloduy-5", *Platts Nuclear Fuel*, 8 February 2021.

received an indefinite operating license for Temelin-2 with a caveat that it meets the continual conditions for safe operation from the regulator, the State Office for Nuclear Safety (SÚJB).[1401]

The Dukovany units were started up during 1985–1987 and have already undergone a lifetime-extension upgrading-program under the expectation they would operate until 2025. In March 2016, the state regulator extended the operating license of Dukovany-1 indefinitely,[1402] with an expectation from the operator that the plant will operate until 2037 with the possibility of extension until 2047.[1403]

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 saying it needed more time to evaluate the impact on its budget and find out EU views on state aid for such a project.[1404] On 13 November 2019, the Czech parliamentary committee for the construction of new nuclear resources approved the construction of the Dukovany II nuclear plant.[1405] Subsequently, Prime Minister Andrej Babis said that they would start construction in 2029 with first power 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.[1406]

Then-Minister of Industry Karel Havlícek told reporters in February 2020 that by the end of 2022 the supplier should be selected.[1407] In March 2020, ČEZ applied to the State Office for Nuclear Safety (SÚJB) for permission to construct two 1,200 MW units at the Dukovany site. In June 2020, the government announced that it had agreed 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. The government said then it was their intention to launch a tender later in 2020.[1408]

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, in order to give the project greater financial security. It was also suggested that the Government is prepared to guarantee the project's 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 investor's expenses.[1409] 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.

1401 - *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 22 June 2022.

1402 - *NucNet*, "Dukovany-2 And -3 To Undergo Extended Checks On Pipe Welds", 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.

1403 - ČEZ Group, "NPP Dukovany", n.d., see http://www.cez.cz/en/energy-generation/nuclear-power-plants/dukovany, accessed 10 May 2021.

1404 - 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.

1405 - *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.

1406 - *NIW*, "Briefs – Czech Republic", *Nuclear Intelligence Weekly*, 15 November 2019.

1407 - *NEI Magazine*, "ČEZ applies to build new nuclear units at Dukovany", *Nuclear Engineering International*, 30 March 2020, see https://www.neimagazine.com/news/newscez-applies-to-build-new-nuclear-units-at-dukovany-7844971/, accessed 9 April 2021.

1408 - Gary Peach, "Prague Announces 70% Financing for Dukovany", *Nuclear Intelligence Weekly*, 5 June 2020.

1409 - Phil Chaffee, "Newbuild: Prague Advances Dukovany Plans", *Nuclear Intelligence Weekly*, 1 May 2020.

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 EPR from EDF ("EPR1200"), both of which are yet to be built anywhere, an AP1000 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—and the Czech Parliament delayed a final decision as the opposition demanded the Rosatom design also be removed.[1410] Subsequently, the government unanimously approved the resolution and then-Deputy Prime Minister Karel Havlícek confirmed that security clearances will only be given to suppliers from France, South Korea and the U.S.[1411]

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—are expected to submit initial bids by the end of November 2022 and complete the bids in 2023, with contracts finalized the following year. The expectation, as expressed by ČEZ Chairman Daniel Benes, is that testing of the new units would begin in 2036.[1412]

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 percent of the construction costs of approximately €7.5 billion (USD7.5 billion); a power purchase agreement for the lifetime of the project; and thirdly, a mechanism to protect utility ČEZ Group and the State in case certain unforeseen events occur, e.g. if Czech law changes and makes the realization of the project impossible. The Commission will review "the appropriateness and proportionality" of the subsidies and their impact on the electricity market.[1413]

In addition to renew reactors at Dukovany, ČEZ is interested in building at Temelin, and in March 2022 announced that they had set aside land for the construction of SMRs.[1414]

In June 2022, in response to ongoing sanctions against Russian assets, the ČEZ Group purchased Škoda JS—an originally Czech nuclear service company—from OMZ, a Russian engineering group controlled by Gazprombanka.[1415]

1410 - *NIW*, "Czech Parliament Delays Dukovany", *Nuclear Intelligence Weekly*, 12 February 2021.

1411 - Phil Chaffee and Gary Peach, "Prague Excludes Rosatom From Dukovany II", *Nuclear Intelligence Weekly*, 23 April 2021.

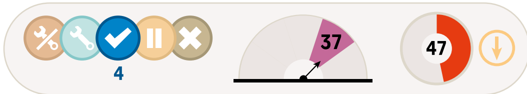
1412 - *NIW*, "News Roundup", *Nuclear Intelligence Weekly*, 18 March 2022.

1413 - *WNN*, "EC examines Czech state aid for new Dukovany plant", 1 July 2022,
see https://www.world-nuclear-news.org/Articles/EC-examines-Czech-state-aid-for-new-Dukovany-plant, accessed 1 July 2022.

1414 - *WNN*, "Space allocated at Temelín for future SMRs", 1 April 2022,
see https://world-nuclear-news.org/Articles/Space-allocated-at-Temelin-for-future-SMR, accessed 7 July 2022.

1415 - *WNN*, "ČEZ buys Škoda JS from Russian owners", 20 June 2022,
see https://www.world-nuclear-news.org/Articles/CEZ-buys-supplier-Skoda-JS-from-Russian-owners, accessed 20 June 2022.

Hungary



Hungary has one operating nuclear power plant, at Paks, where four VVER-440 v213 reactors provided a stable 15.1 TWh or 46.8 percent of the country's electricity in 2021. The nuclear share in the national power mix peaked at 53.6 percent in 2014. The reactors started operation 1982–1987 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 July 2022, the government announced that later this year it would put forward economic and technical plans to further extend the operating lives, by up to 20 years.[1416] In a remarkable turn of events in April 2022, fresh nuclear fuel was flown from Russia, despite EU airspace closure to Russian aircraft, following the awarding of a special permit.[1417]

For over a decade, plans have been discussed and developed to build a new nuclear power plant. In March 2009, the Parliament approved a government decision-in-principle to build additional reactors and a tender was prepared according to European rules. In 2014, the Paks II project was suddenly awarded to Rosatom without reference to the public tender, with Russia financing 80 percent of the project in loans. In February 2017, during a visit to Hungary, Russia's President Putin confirmed that it was even willing to fund 100 percent of the estimated €12 billion (US$$_{2017}$12.9 billion) investment.[1418] The original Russian-Hungarian bilateral financing agreement consisted of a €10 billion (US$11.3 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 billion (US$2.3 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.[1419]

In November 2016, the European Commission cleared the award of the contract to Rosatom of any infringement on its procurement rules, and in March 2017, it also approved the financial package for Paks II.[1420] However, in February 2018 the Austrian Government challenged the validity of the decision, which, as of mid-2022, was still under review by the European Court of Justice.[1421] The legal challenge has subsequently been supported by the Luxembourg Government.

1416 - *NEI Magazine*, "Key licences issued for Paks-II", 6 July 2022, see https://www.neimagazine.com/news/newskey-licences-issued-for-paks-ii-9829343/, accessed 13 July 2022.

1417 - *NEI Magazine*, "Hungary receives Russian nuclear fuel by air", *Nuclear Engineering International*, 11 April 2022, see https://www.neimagazine.com/news/newshungary-receives-russian-nuclear-fuel-by-air-9616933, accessed 7 July 2022.

1418 - *NIW*, "Briefs – Hungary", *Nuclear Intelligence Weekly*, 3 February 2017.

1419 - *WNN*, "Hungary gets agreement to delay Paks II loan repayment", *World Nuclear News*, 30 April 2021, see https://www.world-nuclear-news.org/Articles/Hungary-gets-agreement-to-delay-Paks-II-loan-repay, accessed 1 May 2021.

1420 - *Official Journal of the European Union*, "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 reators at Paks II nuclear power station", L 317/45, European Commission, 1 December 2017, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017D2112, accessed 10 April 2021.

1421 - *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#:~:text=Austria%20has%20launched%20a%20lawsuit,the%20Paks%20nuclear%20power%20plant, accessed 10 April 2021.

The plant was granted an environmental license in September 2016, and in March 2017 the Hungarian Atomic Energy Authority (HAEA) approved the site license for the new construction.[1422] 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.[1423]

In June 2019, a ceremony was held with representatives of Rosatom to mark the start of the erection of buildings at the site and in October 2019, Rosatom handed in the project technical documents. On 30 June 2020, Paks II Ltd. submitted the construction license application to the HAEA. The regulatory procedure started its assessment the next day and HAEA had 12 months to make known its views.[1424] That period could be—and has been—extended by an additional three months.[1425] If all did go 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, HAEA announced that it needs more time "to fully verify all requirements," without giving an updated timeline for approval to construct the new reactors.[1426]

During 2021 and the first half of 2022, developments in the project occurred, nonetheless. In July 2022, the Government announced that further site preparation licenses had been awarded by HAEA, including for soil stabilization and for a 'melt trap',[1427] yet still no construction license was issued.

Power production will therefore likely start later than 2025, as originally envisaged. It had been noted in 2020 that the government had ceased pressing for the project to proceed. Russia, where the economy is suffering, 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 Paks II, which would be borne by the taxpayers.[1428]

In May 2021, the Austrian Federal Environmental Agency published a report which found that the Dunaszentgyörgy-Harta seismic fault passes through the Paks II site and is both an

1422 - *NIW*, "Briefs – Hungary", *Nuclear Intelligence Weekly*, 31 March 2017.

1423 - Gary Peach, "Five Years on, Hungary's Paks Expansion Stumbles Along", *Nuclear Intelligence Weekly*, 8 February 2019.

1424 - HAEA, "Paks II. Ltd. submitted the construction license application to the HAEA", Hungarian Atomic Energy Authority, 30 June 2020, see http://www.oah.hu/web/v3/HAEAportal.nsf/web?OpenAgent&article=news&uid=5B9108F378B8DFBCC1258597003BF3DE, accessed 10 April 2021.

1425 - Hungarian Atomic Energy Authority, "Hirdetmény közzététele az ügyintézési határidő meghosszabbításáról a paksi telephelyen létesítendő 5. és 6. atomerőművi blokkok létesítési engedélyezési eljárásában" ["Notice on the deadline extension for the administrative procedure in the licensing process for the construction of Units 5 and 6 at the Paks Nuclear Power Plant"], 19 May 2021 (in Hungarian), see https://www.haea.gov.hu/web/v3/oahportal.nsf/web?OpenAgent&article=news&uid=4346A8D52E23910EC12586DA0023F45A, accessed 24 May 2021.

1426 - *WNN*, "Paks II construction licence delayed", 1 October 2021, see https://www.world-nuclear-news.org/Articles/Paks-II-construction-licence-delayed, accessed 3 October 2021.

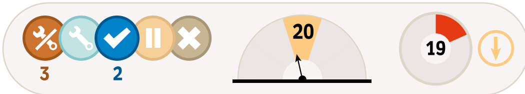
1427 - *NEI Magazine*, "Key licences issued for Paks-II -", 6 July 2022, see https://www.neimagazine.com/news/newskey-licences-issued-for-paks-ii-9829343/; and *WNN*, "Hungary and Rosatom push ahead on Paks II nuclear project", 20 May 2022, see https://www.world-nuclear-news.org/Articles/Hungary-and-Rosatom-push-ahead-on-Paks-II-nuclear; both accessed 13 July 2022.

1428 - Gary Peach, "Hungary: Exorbitant Costs, Solar Energy Remove Luster From Paks II", *NIW*, 22 May 2020.

active and a capable fault. The assessment concludes that "The Paks II site should therefore be deemed unsuitable". 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.[1429]

Despite the economy wide sanctions again Russian companies, according to the Hungarian and Russian authorities, Paks II is proceeding, as nuclear energy is not subject to EU sanctions (yet). In May 2022, Russia's Rosatom gave the Hungarian authorities reassurances that "in terms of technology they are able to complete the project", with Foreign Minister Péter Szijjártó saying he was looking forward to the project entering its next phase.[1430]

Romania



Romania has one nuclear power plant at Cernavoda, where two Canadian-designed CANDU reactors are in operation. In 2021, they provided a stable 10.4 TWh or 18.5 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. Unit 1 was completed in 1996, and Unit 2 started up in 2007, respectively 14 and 24 years after construction 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 CANDU reactors, major refurbishment will be needed after longer operation, and in January 2020 a US$10.8 million contract was signed with Candu Energy, part of the Canadian SNC-Lavalin Group, to undertake engineering analysis and assessments on the fuel channels to enable Unit 1 to operate until a large-scale refurbishment expected to start in 2026 at the time,[1431] now to be carried out in 2027–2029 by SNC-Lavalin.[1432]

Various foreign companies have been involved in the attempts to revive the construction of Units 3, 4, and 5. In November 2013 the Cernavoda operator, state-owned electricity producer Societatea Nationala Nuclearelectrica (SNN) and China General Nuclear (CGN) signed a letter of intent. This was followed in November 2015 with the signing of a Memorandum of Understanding (MoU) between SNN and CGN for the construction, operation and decommissioning of Units 3 and 4. The MoU also included agreements on investments, and

1429 - Eszter Zalan, "Hungary's nuclear power plant expansion unnerves Austria", *EUobserver*, 7 June 2021, see https://euobserver.com/climate/152035, accessed 19 June 2021.

1430 - *WNN*, "Hungary and Rosatom push ahead on Paks II nuclear project", 20 May 2022, see https://www.world-nuclear-news.org/Articles/Hungary-and-Rosatom-push-ahead-on-Paks-II-nuclear, accessed 13 July 2022.

1431 - *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 18 August 2022.

1432 - *NEI Magazine*, "SNC-Lavalin to upgrade Romania's Cernavoda 1", 26 May 2022, see https://www.neimagazine.com/news/newssnc-lavalin-to-upgrade-romanias-cernavoda-1-9727691/, accessed 29 August 2022.

remarkably, CGN was to be the majority share owner of the project with at least 51 percent of the shares.[1433]

In January 2016, the Romania Government formally expressed support for the 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).[1434] 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".[1435]

It is suggested that one of the reasons why the partnership with China has been abandoned is the signing of a nuclear co-operation agreement with the U.S. in August 2019. In October 2020, Adrian Zuckerman, the U.S. ambassador to Romania, said in a speech at the initialing of an intergovernmental 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."[1436] Shortly following this, 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.[1437]

In 2021 and the first half of 2022 progress has been made on the preparatory phase (Stage 1) of the construction project of Units 3 and 4. Stage 1 started with the "capitalization and operationalization" of Energonuclear, the project company and in November 2021 with Energonuclear signing the first contract with Candu Energy, a member of the SNC-Lavalin Group, and the Authority for Designing Units 3 and 4 and OEM Candu (the Original Manufacturer of the Candu Technology). This phase is expected to last 24 months. Stage 2 will then begin with site preparations and is expected to last for 18–24 months; followed by stage 3, the construction phase, expected to last 69–78 months and lead to commissioning of Unit 3 in 2030 and Unit 4 a year later.[1438]

In addition, in November 2021, SNN signed a "teaming agreement" with U.S. small modular reactor (SMR) vendor NuScale to build a 462 MW facility at a former coal plant in Romania "as soon as" 2027–2028.[1439]

1433 - *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, accessed 10 April 2021; and Nuclearelectrica, "The signing of the Memorandum of Understanding regarding the development, construction, operation and decommissioning of Units 3 and 4 of Cernavoda NPP", Press Release, 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, accessed 29 August 2022.

1434 - *WNN*, "Romania expresses support for China's role at Cernavoda", 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.

1435 - *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 18 August 2022.

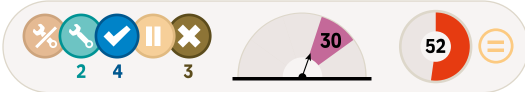
1436 - Stephanie Cooke, "Aecom to Lead $8 Billion Completion of Romania's Cernavoda-3 and -4", *Energy Intelligence*, 7 October 2020, see https://www.energyintel.com/0000017b-a7db-de4c-a17b-e7dbb8d20000, accessed 18 August 2022.

1437 - *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 10 April 2021.

1438 - Nuclearelectrica S.A., "Cernavoda - Units 3 and 4", n.d., see http://www.nuclearelectrica.ro/project-development-activities/units-3-and-4/?lang=en; 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; both accessed 29 August 2022.

1439 - Phil Chaffee, "Romania Talks of Building 'Europe's First SMR'", *Nuclear Intelligence Weekly*, 5 November 2021.

Slovakia



In Slovakia, the state utility Slovenské Elektrárne (SE) operates two nuclear sites, Jaslovské Bohunice, which houses two operating VVER-440 v213 units, and Mochovce, which has two similar reactors. In 2021, their production was a stable 14.7 TWh or 52.3 percent of the country's electricity. Similar to 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.[1440]

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.

Units 1 and 2 at the Mochovce plant were started up in 1998 and 1999 respectively. Modernization and upgrading of the units began in August 2020, increasing their gross output from 471 MWe to 500 MWe. In October 2004, the Italian national utility ENEL (Ente Nazionale per l'Energia Elettrica) acquired a 66 percent stake in SE and, as part of its bid, proposed to invest nearly €2 billion (US$2.7 billion) in new nuclear generating capacity,[1441] including completion of the third and fourth blocks of Mochovce, whose construction originally began in January 1985.

In February 2007, SE announced that it was proceeding with the completion of Mochovce-3 and -4 and that ENEL had agreed to invest €1.8 billion ($\text{US\$}_{2007}$2.6 billion).[1442] According to the IAEA's PRIS, construction restarted in June 2009, and, at the time, the units were expected to generate power in 2012 and 2013 respectively.

Towards the end of 2014, ENEL announced it was seeking to sell its share in SE and had received several non-binding bids. In December 2015, Czech holding EPH (Energeticky a Prumyslovy Holding) was revealed as the bid winner, with a preliminary price of €750 million (US$812 million). Under the deal, ENEL got €150 million (US$171 million) in the first stage, in which EPH received a share of 33 percent in the company, the remaining share and final price to be agreed one year after Mochovce is completed.[1443]

The construction project continued to be plagued by problems, and by May 2016, the estimate for the total costs of completion of Units 3 and 4 had risen to €5.1 billion ($\text{US\$}5.7_{2016}$ billion), with startup at the end of 2016/early 2017.[1444] In March 2017, SE announced a considerable further delay in the project, with operation expected only at the end of 2018 and 2019. This is an additional two years of construction, while the officially expected cost increase announced

1440 - 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 29 August 2022.

1441 - 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 29 August 2022.

1442 - *WNN*, "Contracts signed for completion of Mochovce", 16 June 2009.

1443 - ENEL, "Enel Signs Agreement With EPH for Sale of Stake in Slovenské Elektrarne", 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 28 August 2022.

1444 - *Spravy Pravda*, "Ďalšie peniaze na Mochovce? Žiga nemá oficiálnu informáciu" ["Additional money for Mochovce ?"], 5 May 2016 (in Slovak), see http://spravy.pravda.sk/ekonomika/clanok/392783-dalsie-peniaze-na-mochovce-ziga-nema-oficialnu-informaciu/, accessed 10 April 2021.

simultaneously was only €300 million (US$333 million).[1445] As of early 2018, completion of the projects was still expected at the end of 2018 and 2019.[1446]

In April 2019, Mochovce-3 completed "hot testing" in preparation for fuel loading in the summer, although the regulatory process could at that time still take eight months. A new delay was reported to add an estimated €270 million (US$$_{2019}$305 million) to the cost, representing a 5 percent increase.[1447] However, in September 2019, it was announced that the Nuclear Regulatory Authority (ÚJD) would require further modifications prior to fuel loading.[1448] In January 2020, the nuclear regulator reported two deficiencies in Unit 3 following a second round of hot testing. SE had to submit a plan for corrective action.[1449]

Fuel loading was further delayed, and prior to the COVID-19 pandemic, it was expected at the beginning of the summer of 2020. "In the worst case, it will be the end of 2020" said Branislav Strýček, CEO of SE.[1450] In June 2020, the regulator announced a six month "extension of the period for decision in the administrative proceeding for authorization for commissioning of nuclear installation of the Unit 3".[1451] Furthermore, the regulator found "insufficient documentation of compliance with quality requirements, i.e. the permit holder has yet to complete, supplement or specify documentation proving the quality of certain equipment and work performed".[1452]

In December 2020, an additional loan agreement was made between ENEL and SE for a maximum of US$570 million, to enable the completion of both units. This brought the expected construction 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.[1453]

In May 2021, ÚJD finally issued permits allowing operation as well as related permits for radioactive waste and used fuel management.[1454] The permits are subject to a public comment

1445 - *WNN*, "Slovak utility increases Mochovce expansion budget", 31 March 2017, see http://www.world-nuclear-news.org/NN-Slovak-utility-increases-Mochovce-expansion-budget-31031701.html, accessed 10 April 2021.

1446 - *NIW*, "Briefs—Slovakia", *Nuclear Intelligence Weekly*, 31 January 2020.

1447 - *WNN*, "Mochovce 3 completes commissioning test", 16 April 2019, see https://www.world-nuclear-news.org/Articles/Mochovce-3-completes-commissioning-test, accessed 10 April 2021.

1448 - *NEI Magazine*, "Hot testing of Mohovce 3 revealed the need for further modifications", 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.

1449 - *NIW*, "Briefs—Slovakia", *Nuclear Intelligence Weekly*, 31 January 2020.

1450 - SE, "Mochovce 3: Nuclear authority issued a draft decision on fuel loading", Slovenské Elektrárne, Press Release, 18 February 2020.

1451 - 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, 16 June 2020.

1452 - *NEI Magazine*, "Slovakia's Mohovce 3 commissioning slowed by insufficient documentation", 3 September 2020, see https://www.neimagazine.com/news/newsslovakias-mohovce-3-commissioning-slowed-by-insufficient-documentation-8116778, accessed 7 January 2021.

1453 - *WNN*, "Mochovce new-build project receives loan boost", 24 December 2020, see https://www.world-nuclear-news.org/Articles/Mochovce-new-build-project-receives-loan-boost, accessed 10 April 2021.

1454 - *NEI Magazine*, "Slovak regulator issues permit for commissioning of Mochovce 3", 17 May 2021, see https://www.neimagazine.com/news/newsslovak-regulator-issues-permit-for-commissioning-of-mochovce-3-8749322, accessed 5 July 2021.

period, which started on 4 June 2021, with a 15-day window for appeals. The Austrian Government has objected to the licensing and asked for an independent assessment.[1455]

In January 2022 ÚJD published its draft decision to permit the commissioning of Mochovce-3, with comments allowed until the end of March, following various legal challenges from the Austrian Environmental Group Global 2000.[1456] In February 2022, Global 2000 published a series of pictures of corrosion effects at the reactor pressure vessel (see Figure 71).[1457] As of mid-2022, "the start-up of Unit 3 is currently scheduled to take place at the end of 2022, while the start-up of Unit 4 is planned in 2024", according to the latest update by Škoda—one of the project's main suppliers.[1458]

"The regulator found "insufficient documentation of compliance with quality requirements, i.e. the permit holder has yet to complete, supplement or specify documentation proving the quality of certain equipment and work performed""

The Ministry of Energy had said in the past that once the reactor is fully operational, the country will become a net exporter of electricity in 2022.[1459]

As with other countries in the region concern over dependency on Russia for energy is not restricted to fossil fuels, as Russia has been in Slovakia the monopoly supplier of nuclear material. Consequently, Slovenske Elektrarne has begun negotiations on the possible supply of fuel assemblies for the Slovakian nuclear operator's four VVER-440 reactors. Westinghouse is currently the only western provider of VVER fuel.[1460]

1455 - Christoph Matzl, "AKW-Löschsystem entspricht Standards nicht: "Feuer am Dach" in der Atomruine Mochovce", *Kronen Zeitung*, 18 June 2021 (in German), see https://www.krone.at/2440644, accessed 5 July 2021.

1456 - *WNN*, "Mochovce 3 to get commissioning licence", 26 January 2022, see https://www.world-nuclear-news.org/Articles/Mochovce-3-to-get-commissioning-licence, accessed 22 April 2022.

1457 - Global 2000, "GLOBAL 2000 reports Slovak Nuclear Authority to the criminal police in Slovakia NAKA", Press Release, 24 February 2022, see https://www.global2000.at/en/node/7205, accessed 29 August 2022.

1458 - ŠKODA JS a.s, "Units 3 and 4 at Mochovce NPP, Slovakia", Update 2022, see https://www.skoda-js.cz/reference/nuclear-powerplant-mochovce/, accessed 17 August 2022.

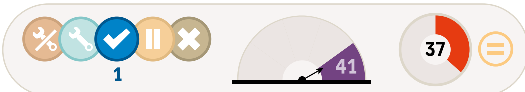
1459 - *WNN*, "New nuclear reactor will make Slovakia a power exporter", 17 August 2021, see https://www.world-nuclear-news.org/Articles/New-nuclear-reactor-will-make-Slovakia-a-power-exp, accessed 22 August 2021.

1460 - Andy Bounds and Marton Dunai, "Brussels to help EU countries end reliance on Russian nuclear fuel", *Financial Times*, 19 May 2022, see https://www.ft.com/content/fcce8ccc-31bd-4dab-8532-12cd0948fc5d;
also Michal Hudec, "Statistics underplay Slovak dependence on energy imports", *Euractiv*, 10 June 2022, see https://www.euractiv.com/section/energy-environment/news/statistics-underplay-slovak-dependence-on-energy-imports/, both accessed 29 August 2022.

Figure 71 · Corrosion at Mochovce-3 Reactor Pressure Vessel Prior to Startup

Source: Global 2000

Slovenia



Slovenia jointly owns the Krško nuclear power plant with Croatia—a 688-MW Westinghouse PWR. In 2021, it provided 5.4 TWh or 36.9 percent of Slovenia's electricity, a nuclear share well below the maximum of 42.4 percent in 2005.

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, are not opposed to nuclear power 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.[1461]

The Krško reactor is built in an earthquake zone and on 29 December 2020 it was shut down temporarily following a 6.3 magnitude seismic event close to the town of Petrinja in the Zagreb region, around 30 km from the plant.[1462]

The reactor was started in 1981 with an initial operational life of 40 years. In July 2015, an Inter-State Commission agreed to extend the plant's operational lifetime to 60 years, so that it would continue until 2043, as well as to construct a dry storage facility for the spent fuel. In May 2016, a spokeswoman for the operator NEK (Nuklearna Elektrarna Krško), part of the GEN Group, said: "The lifespan of Krško has been extended providing that the plant passes

1461 - 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.

1462 - *NEI Magazine*, "Krsko nuclear plant restarts after earthquake triggers shutdown", 4 January 2021, see https://www.neimagazine.com/news/newskrsko-nuclear-plant-restarts-after-earthquake-triggers-shutdown-8435716/, accessed 10 April 2021.

a security check every 10 years with the next checks due in 2023 and 2033."[1463] In 2018, the operator announced around €50 million (US$57 million) worth of investment being planned for 2019, mostly for completing safety upgrades (partially implementing findings of EU post-Fukushima stress tests) and replacing obsolete equipment. The first outage for that was undertaken in October 2019, followed by a second one in April 2021, which lasted one month.

On 25 March 2021, the Austrian Parliament voted unanimously a resolution instructing the Government to "use all diplomatic, legal, and political means on the bilateral and European level" to prevent the lifetime extension of Krško and any newbuild option there.[1464]

A petition requesting the closure of the Krško reactor launched by Global 2000 was signed by over 61,000 Austrian individuals by April 2022. In addition, over 6,400 Austrians submitted comments in that direction in the framework of a comprehensive transboundary Environmental Impact Assessment (EIA) procedure on Slovenia's lifetime extension project for Krško.[1465] An Austrian Government commissioned assessment of Slovenia's EIA report from the Austrian Environment Agency (Umweltbundesamt) concluded:

- **Alternatives exist.** Studies have shown that by 2030 over half of Slovenia's electricity demand could be provided by solar PV and wind (onshore).
- **No final repository.** The EIA "did not report about the progress" of activities aiming at a joint Slovenian/Croatian geological repository for spent fuel to start operating in either 2065 or 2093.
- **Safety unclear.** "Even though significant improvements have been made, it is not clear whether the achieved safety level (especially with regard to earthquakes) is sufficient." The EIA does not mention "the concept of 'practical elimination' of early or large releases".
- **Earthquake resistance questionable.** The seismic hazard had been reassessed and doubled in 2004 and 2014. The EIA documents "do not provide evidence of the resistance of the existing structures and systems" based on the reassessed peak ground acceleration.
- **Deficiencies in physical protection.** A recent assessment of the nuclear security in Slovenia points to "shortcomings compared to necessary requirements for nuclear security."
- **Transboundary impacts.** The report concludes: "Overall, such accidents with corresponding significant impacts on Austrian territory cannot be ruled out at this stage."[1466]

Should the EIA process and eventual ensuing backfitting work not be completed by the end of 2023, Krško would have to be closed.

1463 - *NEI Magazine*, "Life extension for Slovenia's Krsko NPP", 6 May 2016, see http://www.neimagazine.com/news/newslife-extension-for-slovenias-krslo-npp-4885976/, accessed 10 April 2021.

1464 - Austrian Parliament, "Entschließung des Nationalrates vom 25. März 2021 betreffend Nein zur Betriebsverlängerung des AKW Krsko" ["National Council Resolution of 25 March 2021 Regarding 'No' to the extended operation of the Krško NPP"], Republic of Austria, 25 March 2021 (in German), see https://www.parlament.gv.at/PAKT/VHG/XXVII/E/E_00158/fnameorig_936888.html, accessed 30 July 2022.

1465 - Global 2000, "Über 61.000 Unterschriften gegen das AKW Krsko" ["Over 61,000 Signatures Against the Krško NPP"], 12 April 2022, see https://www.global2000.at/news/ueber-61000-unterschriften-gegen-das-akw-krsko, accessed 30 July 2022.

1466 - Environment Agency Austria and BIEGE Nuklearexpertise, "Umweltverträglichkeitsprüfung—KKW Krško/Slowenien—Laufzeitverlängerung" ["Environmental Impact Assessment—NPP Krško/Slovenia—Lifetime extension"], Umweltbundesamt, commissioned/published by Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation, and Technology, 2022, see https://www.umweltbundesamt.at/uvp-kkw-krsko-lte, accessed 30 July 2022.

Meanwhile, in Spring 2022, the IAEA has undertaken an Integrated Regulatory Review Service (IRRS) at Krsko and found that Slovenia is continuously working to further strengthen its "mature" nuclear and radiation safety framework. However, it did note that further improvements could be made e.g. in "developing communication strategies and plans to ensure the stakeholders are informed about their work" and on "developing guidance for licensees on the use of authorization request documents".[1467]

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.

In May 2022, GEN provided the following overview of the project status: [1468]

- 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,
- 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 Ministry for Environment.

The assumption is 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 AP1000 and EDF with an EPR1200 termed version of the EPR.[1469] 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, Westinghouse's only AP1000 construction project in the U.S. has been under construction for over nine years, and the EPR does not exist yet and has not even been licensed anywhere in the world, the official JEK-2 schedule presented appears highly unrealistic.

Responding to a question what the Plan B 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.[1470] Energy experts from the Association of Ecological Movements of Slovenia are pointing to the relatively high final energy consumption in Slovenia—7 percent above EU 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

1467 - IAEA, "IAEA's Regulatory Review in Slovenia Finds Mature Safety Framework, Suggests Actions for Improved Performance", Press Release 69/2022, 14 April 2022, see https://www.iaea.org/newscenter/pressreleases/iaeas-regulatory-review-in-slovenia-finds-mature-safety-framework-suggests-actions-for-improved-performance, accessed 18 August 2022.

1468 - Bruno Glaser and Tomaž Žagar, "GEN's vision for decarbonisation and energy independence – by 2035", GEN Energija, May 2022

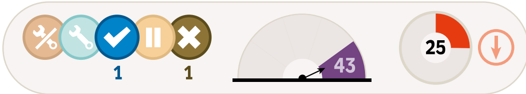
1469 - Ibidem.

1470 - 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.

electricity, entirely from renewable energy sources, if we reduce energy waste and use the available renewable energy sources. Free of fossil and nuclear energy."[1471]

FORMER SOVIET UNION

Armenia



Armenia has one remaining reactor at the Metsamor nuclear power plant, situated within 30 kilometers of the capital Yerevan. The Armenian-2 called reactor provided 1.8 TWh or 25.3 percent of the country's electricity in 2021, down from a maximum nuclear share of 45 percent in 2009.

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 major 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 resulted in an energy blockade that resulted in power shortages which led to the Government's decision in 1993 to re-open Unit 2. Since 2003, the plant is operated by InterRAO, a subsidiary of Russian Rosatom, as part of an arrangement to repay debts to Rosatom's TVEL fuel supplier.

In October 2012, the Armenia Government announced that it planned to operate Metsamor until 2026. The lifetime extension was made possible by a Russian loan of US$270 million and a US$30 million grant. In 2011, the Armenian Nuclear Regulatory Authority had granted the reactor an extension of its operating license until 2021, subject to annual safety demonstrations starting 2016.[1472] The engineering work that will enable the reactor to operate until 2026 was completed in November 2021.[1473]

In June 2016, the European Nuclear Safety Regulators Group (ENSREG) issued the "EU Peer Review Report of the Armenian Stress Tests[1474] confirming numerous safety-related problems. In September 2017, the European Commission published its proposed partnership agreement with Armenia, which included recommendations for co-operation on "the closure and safe decommissioning of Metsamor nuclear power plant and the early adoption of a road map or action plan to that effect."[1475] Opposition parties in Turkey called on their Government in December 2019 through a parliamentary resolution to take steps to resolve the risks posed by Metsamor.

1471 - Matjaž Valenčič, "The future of Slovenia: Renewable energy, without fossil and nuclear", 18 May 2022, unpublished.

1472 - *NEI Magazine*, "Armenian NPP to close for refurb", 21 March 2019, see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023/, accessed 10 April 2021.

1473 - *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 7 July 2022.

1474 - 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 10 April 2021.

1475 - European Commission, "Annex to the Joint Proposal for a Council Decision on the conclusion, on behalf of the European Union, of the Comprehensive and Enhanced Partnership Agreement between the European Union and the European Atomic Energy Community and their Member States, of the one part and the Republic of Armenia, of the other part.", 25 September 2017, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017JC0037, accessed 10 April 2021.

In February 2020, Government officials said that they were considering, as part of the country's 2040 energy strategy, further extending the life of the reactor along with measures to increase its output by 12-15 percent.[1476] A consequence of the program is the closure of the unit for at least 140 days in 2021. The energy strategy also says that, if the safe operation is confirmed, the government will operate the facility at least until 2036, which is expected to require additional investments of US$150 million.[1477] The plan also includes proposals for the construction of an additional reactor.[1478]

For years, Armenia has been negotiating with Russia for the construction of a new 1000 MW unit and signed an intergovernmental agreement to that effect in August 2010.[1479] In January 2022, Rosatom, of Russia, and the management of Metsamor signed an agreement to 'look into the possible building' of a new power plant in Armenia.[1480] While in May 2022 the US and Armenian Governments signed an MoU on civil nuclear power, including, on cooperation on energy security and strengthening diplomatic and economic relationship.[1481]

In March 2020, the European Commission published a Communication proposing a new "Eastern Partnership Policy Beyond 2020", which included recommendations on energy policy and nuclear power. Furthermore, it acknowledges that countries may choose nuclear power but that "the EU's forerunner role in binding nuclear legislation will be the basis of further bilateral exchanges. We will continue to organize nuclear stress test peer reviews and follow-up activities".[1482]

The power plant remains a source of continual tension with neighboring Azerbaijan and in July 2020 a senior Azerbaijani official threatened a missile strike against Metsamor during renewed fighting on the Armenia-Azerbaijan border. Furthermore, Galib Israfilov, Azerbaijan ambassador to the IAEA, 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."[1483]

While 2021/2 has been significant, in that the engineering work to enable the power plant to operate until 2026 was completed, time is running out for the power plant. Even under the most optimistic scenarios it will be at least decade before a new nuclear power plant can be operational, and so the country needs to accelerate its planning for a non-nuclear future.

1476 - *NEI Magazine*, "Armenia considers further life extension for Metsamor", 2 March 2020, see https://www.neimagazine.com/news/newsarmenia-considers-further-life-extension-for-metsamor-7802500, accessed 10 April 2021.

1477 - *NEI Magazine*, "Armenia to extend nuclear plant service beyond 2026", 18 January 2021, see https://www.neimagazine.com/news/newsarmenia-to-extend-nuclear-plant-service-beyond-2026-8457690/, accessed 10 April 2021.

1478 - Phil Chaffee, "Interview: Azerbaijan Eager for Mechanism to Address Metsamor Concerns", *Nuclear Intelligence Weekly*, 7 August 2020.

1479 - *Arka News Agency*, "Minister: Armenia not to give up the idea of building new nuclear power plant", 20 October 2017, see http://arka.am/en/news/technology/minister_armenia_not_to_give_up_the_idea_of_building_new_nuclear_power_plant/, accessed 10 April 2021.

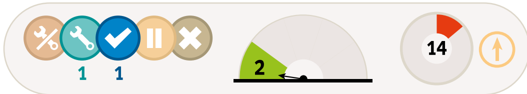
1480 - *WNN*, "Rosatom signs agreement on possible new reactors for Armenia", 21 January 2022, see https://www.world-nuclear-news.org/Articles/Rosatom-signs-agreement-on-possible-new-reactors-f, accessed 11 September 2022.

1481 - *NEI Magazine*, "US and Armenia sign MOU on civil nuclear cooperation", 5 May 2022, see https://www.neimagazine.com/news/newsus-and-armenia-sign-mou-on-civil-nuclear-cooperation-9675799/, accessed 7 July 2022.

1482 - High Representative of the Union for Foreign Affairs and Security Policy, "Joint Communication to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions—Eastern Partnership Policy Beyond 2020—Reinforcing Resilience – an Eastern Partnership That Delivers For All", 18 March 2020, see https://eeas.europa.eu/sites/eeas/files/1_en_act_part1_v6.pdf, accessed 11 September 2022.

1483 - Phil Chaffee, "Interview: Azerbaijan Eager for Mechanism to Address Metsamor Concerns", *NIW*, 2020, op. cit.

Belarus



Construction started in November 2013 at Belarus's first nuclear reactor at 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.[1484] In May 2022, the Deputy Energy Minister Mikhail Mikhadyuk said that work on the second unit at the country's first nuclear power plant is proceeding on schedule, with grid connection expected before the end of the year and that the feasibility of building a second nuclear power plant in the country is being assessed.[1485]

In 2021, the reactor provided 5.4 TWh, representing a share of 14 percent of the electricity production.

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 occurred in the first month (later confirmed by Belarus), including in the voltage transformer, the cooling system, and a steam noise absorber.[1486] On 2 June 2021, Belarusian-1 received a commercial operating license.[1487]

The European Commission issued a statement saying "It is regrettable that Belarus has decided to start the commercial operation of the Astravets [Ostrovets] nuclear power plant, without addressing all the safety recommendations contained in the 2018 EU stress test report. As the Commission has repeatedly stated, all peer review recommendations should be implemented by Belarus without delay."[1488]

The State Inspectorate for Nuclear Energy Safety of Lithuania (Vatesi) commented: "The fact of issuing a licence does not change the position of Vatesi, that it is necessary to suspend the operation of the Belarusian NPP, resolve nuclear safety problems and take the necessary measures to improve its safety."[1489]

In October 2011, a contract was signed between the Belarus Nuclear Power Plant Construction Directorate, and Russia's AtomStroyExport (ASE). It defines the main terms of the general contract for the construction of two reactors as a turnkey project to be carried out by ASE, with the first unit then scheduled to be commissioned in 2017 and the second in 2018.[1490] The

1484 - *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 1 May 2021.

1485 - *WNN*, "Belarus's 2022 plan for second unit at Ostrovets 'on schedule'", 12 May 2022, see https://www.world-nuclear-news.org/Articles/Belarus-aims-to-launch-second-unit-of-nuclear-powe, accessed 7 July 2022.

1486 - Andrew Rettman, "Lithuania warns EU leaders on Belarus nuclear incidents", *EUobserver*, 11 December 2020, see https://euobserver.com/foreign/150358, accessed 1 May 2021.

1487 - Gosatomnadzor, "License for the Operation of Belarusian NPP Power Unit No. 1 is issued", 2 June 2021, see http://gosatomnadzor.mchs.gov.by/en/novosti/353948/, accessed 30 July 2021.

1488 - European Commission, "Statement by Commissioner Simson on the Astravets nuclear power plant in Belarus", 2 June 2021, see https://ec.europa.eu/commission/commissioners/2019-2024/simson/announcements/statement-commissioner-simson-astravets-nuclear-power-plant-belarus_en, accessed 12 August 2021.

1489 - *NEI Magazine*, "Issue of operating licence for Belarus unit 1 prompts protests from Lithuania", 8 June 2021, see https://www.neimagazine.com/news/newsissue-of-operating-licence-for-belarus-unit-1-prompts-protests-from-lithuania-8803313, accessed 30 July 2021.

1490 - *WNN*, "Contract signed for Belarusian reactors", 11 October 2011, see https://www.world-nuclear-news.org/Articles/Contract-signed-for-Belarusian-reactors, accessed 1 May 2021.

Russian and Belarusian governments agreed that Russia would lend up to US$10 billion for 25 years to finance 90 percent of the project. In July 2012, the contract was signed for the construction of the two reactors for an estimated cost of US$10 billion, including US$3 billion for new infrastructure to accommodate the remoteness of Ostrovets in northern Belarus.[1491] Under the terms of the loan agreement Belarus should begin to repay the loan no later than 1 April 2021. Furthermore, the current loan rate for Belarus is a fixed 5.23 percent a year for half of the selected funds and "six-month LIBOR[1492] in dollars (now 1.72 percent) plus 1.83 percent per annum" for the other half. Belarus has also proposed increasing the repayment period from 25 years (counting from the date of opening a credit line in 2011) to 35 years, but this has so far been rejected by the Russian counterparts. In March 2021, the Russia-Belarusian loan agreement was adjusted, and the loan extended by two years, until the end of 2022. In addition, a fixed interest rate on the loan is set at 3.3 percent a year, and the start date of the repayment of the principal debt on the loan has been deferred from 1 April 2021 to 1 April 2023.[1493]

The project assumes liability for the supply of all fuel and repatriation of spent fuel for the life of the plant. The fuel is to be reprocessed in Russia and the separated wastes returned to Belarus. Information is not available on the fate of the plutonium extracted during reprocessing, but it is likely to remain in Russia.

It is difficult to estimate what the final construction price will be. On the one hand, President Lukashenko has said 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."[1494] Other sources suggest that the cost of the project has increased by 26 percent, to 56 billion Russian rubles [US$750 million] in 2001-prices.[1495] The uncertainty of the actual costs is compounded by the high volatility of exchange rates.

Since its early stages, the project has been the focus of international opposition and criticism, with formal complaints from the Lithuanian government[1496] that has published a list of fundamental problems of the project. These include claims of major construction issues, doubts about the site suitability and accusations of non-compliance with some of its public engagement obligations according to the Espoo Convention. Belarus was in 2017 found in non-compliance with the Aarhus Convention for harassing members of civil society campaigning against the project.[1497] Then, in February 2019, a meeting of the Espoo Convention voted by 30

1491 - *NIW*, "Belarus, Aided by Russia and Broke, Europe's Last Dictatorship Proceeds With NPP", 28 September 2012.

1492 - The London Interbank Offered Rate (LIBOR) is a benchmark interest rate at which major global banks lend to one another in the international interbank market for short-term loans.

1493 - *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/, accessed 1 May 2021.

1494 - *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 1 May 2021.

1495 - *Charter 97*, "Astravets NPP Becomes 12 Billion More Expensive In One Day", 30 December 2016, see https://charter97.org/en/news/2016/12/30/236059/, accessed 1 May 2021.

1496 - Bryan Bradley, "Lithuania Urges Belarus to Halt Nuclear Project on Safety Issues", *Bloomberg*, 20 August 2013, see https://www.bloomberg.com/news/articles/2013-08-20/lithuania-urges-belarus-to-halt-nuclear-project-on-safety-issues, accessed 1 May 2021.

1497 - Economic Commission for Europe, "Findings and recommendations with regard to communication ACCC/C/2014/102 concerning compliance by Belarus", Economic and Social Council, United Nations, presented at Meeting of the Parties to the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters – 58th Meeting 10-13 September 2017, Adopted by the Compliance Committee 18 June 2017, Distributed 24 July 2017, see https://www.unece.org/fileadmin/DAM/env/pp/compliance/CC-58/ece.mp.pp.c.1.2017.19.e.pdf, accessed 1 May 2021.

to 6 that Belarus had violated the convention's rules while choosing Ostrovets as the site for a nuclear power plant.[1498]

The Belarussian government, in order to allay European concerns about Ostrovets, submitted the project to a post-Fukushima nuclear stress test and produced a national report, which was submitted to peer-review by a commission from the European Nuclear Safety Regulators Group (ENSREG) and the European Commission. In July 2018, the European Commission announced that the ENSREG report had been presented to the Belarussian authorities and the executive summary was made public, which concludes that "although the report is overall positive, it includes important recommendations that necessitate an appropriate follow up". For example, on the topic of assessment of severe accident management, it says, "the overall concept of practical elimination of early and large releases should be more explicitly reflected in an updated plant safety case." It also gave recommendations for better seismic robustness.[1499]

The Belarus authorities have not responded to the peer-review report and in June 2019 the Council of the European Union stated, "The Commission and ENSREG have been calling upon Belarus to swiftly prepare and present a National Action Plan to address the peer-review findings and recommendations, in line with the practice followed for previous stress tests within the EU and with third countries. At the moment of preparation of this report, the Commission and ENSREG are still awaiting reception of this plan."[1500] The Lithuanian President has called upon the European Commission to take all possible actions to ensure the safety of the power plant and in March 2020, the Belarus nuclear regulator discussed the national action plan with ENSREG.[1501] A follow-up mission of ENSREG in February 2021 to discuss the (lack of) implementation of the stress-test recommendations was downscaled due to the COVID pandemic and was to be followed by a larger mission in May–June 2021[1502], but had not been reported as of mid-August 2021.

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 EU stress test recommendations are fully implemented and all necessary safety improvements are in place".[1503]

Belarus has historically been an importer of electricity from Russia and Ukraine. Lithuania is trying to get its neighbors to follow the ban on nuclear power from Belarus and will use the Espoo ruling to add weight to its claim. In February 2020, the Governments of Estonia, Latvia and Lithuania issued a joint declaration that they would oppose electricity purchases

1498 - *NIW*, "Briefs – Belarus", *Nuclear Intelligence Weekly*, 15 February 2019.

1499 - ENSREG, "Belarus Stress Tests Peer Review–Executive Summary", June 2018, see http://www.ensreg.eu/sites/default/files/attachments/hlg_p2018-36_156_belarus_stress_test_prt_report_-_executive_summary_0.pdf**d**., accessed 12 August 2021.

1500 - European Atomic Energy Community, "Report on the implementation of the obligations under the Convention on Nuclear Safety – 8th Review Meeting of the Contracting Parties", Council of the European Union, 19 June 2019, see https://data.consilium.europa.eu/doc/document/ST-10365-2019-ADD-1/en/pdf, accessed 1 May 2021.

1501 - *BelTA*, "Fulfillment of national action plan in wake of Belarusian nuclear power plant stress tests reviewed", 11 March 2020, see https://atom.belta.by/en/belaes_en/view/fulfillment-of-national-action-plan-in-wake-of-belarusian-nuclear-power-plant-stress-tests-reviewed-10573/, accessed 1 May 2021.

1502 - *BelTA*, "Belarus to host ENSREG mission in May-June", 15 February 2021, see https://eng.belta.by/economics/view/belarus-to-host-ensreg-mission-in-may-june-137467-2021/, accessed 4 May 2021.

1503 - European Parliament, "European Parliament 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.

from the nuclear power plant.[1504] In addition, in May 2020, the Lithuanian Parliament passed a resolution "on Energy Independence and the Threat Posed by the Astravyets Nuclear Power Plant" proposing that the government take technical means to block electricity from Belarus.[1505] The sale of electricity to the West will be vital for the economics of the project, as increasing domestic consumption or even sale back to Russia will raise significantly lower revenues, due to lower prices. The inability to export the power will lead to significant overcapacity and consequently President Alexander Lukashenko has said that the government needed to devise ways to get the population to use more electricity, including retrofitting houses for electric heating and installing more water boilers.[1506]

In November 2020, following the first production of power from Unit 1, Lithuanian transmission system operator Litgrid ceased all power trading with Belarus.[1507] However, trading did restart, and Lithuania is seeking a permanent solution. In March 2021 the Government proposed a new trilateral methodology for power trade with Russia to its Baltic neighbors with the hope that this would lead to a blockade of electricity from Belarus.[1508] It is foreseen that the Baltic states will be synchronized with the West-European electricity grid in 2025, delinking the region from its dependency on Russian and Belarusian electricity.[1509] Following the start of commercial operation Lithuania initiated a legal process to take control of power interconnections with Belarus. The Lithuania government hopes that restricting electricity exports will delay the commercial operation of Belarus-2.

In response to the war in Ukraine electricity import from Russia into EU member states has come under scrutiny and in May the power exchange Nord Pool has decided to stop trading Russian electricity from its only importer in the Baltic States, Russian utility Inter RAO.[1510]

1504 - 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 1 May 2021.

1505 - Sniegė Balčiūnaitė, "Lithuanian parliament ups the ante on Belarus nuclear plant", *LRT*, 5 May 2020, see https://www.lrt.lt/en/news-in-english/19/1175343/lithuanian-parliament-ups-the-ante-on-belarus-nuclear-plant, accessed 1 May 2021.

1506 - Gary Peach, "Belarus Prepares Reactor Launch Despite Covid-19 Surge", *NIW*, 29 May 2020.

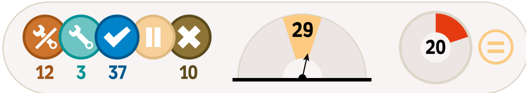
1507 - Andrius Sytas, "Lithuania stops Baltics power trade with Belarus, Russia over nuclear plant", *Reuters*, 3 November 2020, see https://www.reuters.com/article/litgrid-belarus-idUSKBN27J2CA, accessed 1 May 2021.

1508 - *The Baltic Times*, "Lithuania expects to agree with neighbors by July on Belarus' nuclear power blockade", 2 March 2021, see https://www.baltictimes.com/lithuania_expects_to_agree_with_neighbors_by_july_on_belarus__nuclear_power_blockade/, accessed 1 May 2021.

1509 - Evelin Szőke, "Baltic states' mega project of synchronisation to receive 720 mln euros of EU support", *CEENERGYNEWS*, 5 October 2020, see https://ceenergynews.com/electricity/baltic-states-mega-project-of-synchronisation-to-receive-720-mln-euros-of-eu-support/, accessed 4 May 2021.

1510 - *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 2022.

Russia



In 2021, nuclear energy contributed 20 percent to the country's electricity mix with another record production of 208.5 TWh of electricity.

2021 did not see the start of any new reactors, unlike the previous year with Leningrad 2-2,[1511] but did see the closure of Unit 1 at the Kursk, a 925 MW Chernobyl-type RBMK in December. Consequently, as of mid-2022, 37 reactors are operating and ten have been permanently closed.

Two large reactors remain under construction at Kursk II, which is a particularly important project, as they would be the first of the latest Russian design, the VVER-TOI (VVER-V-510). These are 1200 MW, Generation III+ design, and are also earmarked for export. When construction started on Unit 1, completion was scheduled for late 2023, and in June 2021, the first deputy director for construction claimed that the project was on schedule.[1512]

In June 2020, Rosenergoatom announced that preparation work would begin for the construction of four new reactors, Units 3 and 4 at Leningrad II as well as two reactors at Smolensk.[1513] In June 2021, Rosatom said it has started construction of an innovative fast reactor that will use liquid lead as a coolant and uranium-plutonium nitride for fuel. The objective for the BREST-OD-300 reactor is to operate by 2026 and it is said to cost 100 billion rubles (US$1.4 billion).[1514]

Construction started at Baltic-1, a 1109 MW VVER-491 reactor project, in February 2012. However, construction was suspended in June 2013 for a variety of reasons, including recognition of the limited market for electricity. Accordingly, WNISR has removed it from the project construction listing. Despite no indication that construction has ever restarted, the project remains "under construction" in IAEA-PRIS statistics.

In August 2016, a Government decree called for the construction of an additional 11 reactors by 2030, including two new Fast Breeder Reactors (FBRs), a VVER-600 at Kola, and seven new VVER–TOI units at Kola, Smolensk, Nizhny Novgorod, Kostrom, and Tatar.[1515] In early 2017, the CEO of Rosatom said that the Government would end state support for the construction of new nuclear units in 2020, and therefore any new reactors would have to be financed primarily via commercial nuclear energy projects on the international market. Even before this date, the budget for construction of new reactors was expected to be a modest US$250–280 million in the period 2018–2020,[1516] which may explain the lack of new construction in Russia beyond Kursk II.

1511 - *NEI Magazine*, "Leningrad-II-2 begins commercial operation", 23 March 2021, see https://www.neimagazine.com/news/newsleningrad-ii-2-begins-commercial-operation-8618701/, accessed 10 April 2021.

1512 - *NEI Magazine*, "Russia's Kursk II on Schedule", 2 June 2021, see https://www.neimagazine.com/news/newsrussia-kursk-ii-on-schedule-8781839, accessed 20 July 2022.

1513 - *WNN*, "Russia begins preparatory work for four new reactors", 26 June 2020, see https://www.world-nuclear-news.org/Articles/Russia-begins-preparatory-work-for-four-new-reacto, accessed 10 April 2021.

1514 - *NIW*, "Construction Starts on Lead-Cooled Fast Reactor", *Nuclear Intelligence Weekly*, 11 June 2021.

1515 - *WNN*, "Russia to build 11 new nuclear reactors by 2030", 10 August 2016, see https://www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html#:~:text=A%20Russian%20government%20decree%20published,sodium%2Dcooled%20fast%20neutron%20reactors, accessed 10 April 2021.

1516 - *NIW*, "Briefs – Russia", *Nuclear Intelligence Weekly*, 22 September 2017.

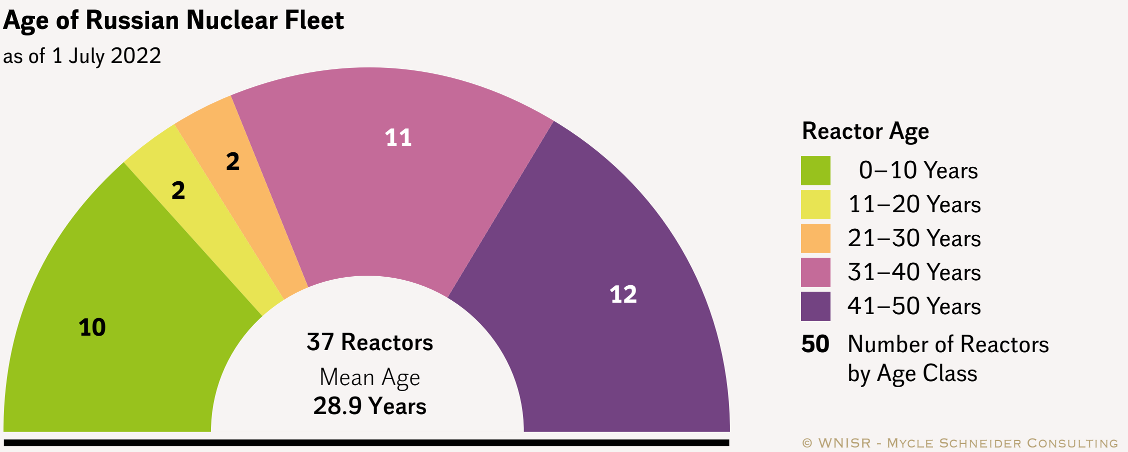
In March 2021, in its strategic review, Rosatom said that by 2045 nuclear should provide 25 percent of the country's electricity. This will, according to Rosatom CEO Alexei Likhachev, require the commissioning of 24 units, including at new sites and in new regions.[1517] This plan was re-announced in May 2022 by Rosatom.

The list of new reactors in a plan to 2035, includes: Kursk-II: Units 1–4 (VVER-TOI); Leningrad-II: Units 3 & 4 (VVER-1200); Smolensk-II: Units 1 & 2 (VVER-TOI); four modernized "floating reactors" (RITM-200) for Baimsky and one for Yakutia; Seversk, BREST-OD-300 fast reactor; Kola-II: Unit 1 (VVER-S or VVER-600); and Beloyarsk: Unit 5 (BN-1200 fast reactor).[1518]

However, it was reported that Rosatom received a budget of only 880 billion rubles (US$11 billion) and not the requested 1.16 trillion rubles (US$15.6 billion) for construction through to 2035. In the summer of 2020, Rosatom announced that it would build four new reactors (two VVER-1200 and two VVER-TOIs) to replace the aging RBMKs.[1519] Commissioning of the fast reactor at Beloyarsk was delayed from 2027 to 2036. Therefore, with actual construction ongoing on only three units, it is extremely unlikely that any of these reactors will be operational by the start of the next decade.

Russia has closed ten power generating reactors: Obninsk-1, Beloyarsk-1 and -2, Bilibino-1, Leningrad-1 and -2, Kursk 1 and Novovoronezh 1–3, with a further 10 units to potentially close by 2030.[1520] The average age of the Russian reactor fleet is now 28.9 years, with close to two thirds being 31 years or more, of which 12 operated for 41 years or more (see Figure 72). Therefore, a key issue for the industry is how to manage its aging units.

Figure 72 · Age Distribution of the Russian Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2022

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.

1517 - *NEI Magazine*, "Rosatom's development plans", 11 March 2021, see https://www.neimagazine.com/news/newsrosatoms-development-plans-8592063/, accessed 10 April 2021.

1518 - *NEI Magazine*, "Russia to build 16 new nuclear units by 2035", 1 June 2022, see https://www.neimagazine.com/news/newsrussia-to-build-16-new-nuclear-units-by-2035-9738009/, accessed 19 July 2022.

1519 - Gary Peach, "Rosatom Orders Four Reactors To Replace Aging RBMKs", *Nuclear Intelligence Weekly*, 17 July 2020.

1520 - *NEI Magazine*, "Russia to build 16 new nuclear units by 2035", 1 June 2022, op. cit.

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. There are plans to extend the operating life in some cases to 60 years[1521], while the VVER-1000s are expected to work for up to 50 years. Consequently, the closure of Leningrad-1 and -2 is potentially a significant event, as, after 45 years of operation, it would indicate that 60-year operational lifetime is beyond the RMBK potential.

The country also has two Fast Breeder Reactors (FBRs) in operation at Beloyarsk. The older and smaller of the two reactors is a 600 MW unit, which started 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,[1522] but plans are being developed to enable the unit to operate for 60 years. The BN-800 is in the course of converting from high enriched uranium (HEU) to mixed oxide plutonium-uranium (MOX).[1523] In June 2022, it was shut down for maintenance and refueling, after which it will be fully loaded with MOX fuel.[1524] The new VVER-1200 reactors in Novovorenezh II and Leningrad II have a design lifetime of 60 years, with plans to extend this to 80. The floating KLT-40 reactors on the Akademik Lomonosov are designed for three or four 12-year operational cycles.

Russia is an aggressive exporter of nuclear power, with, according to Rosatom, 35 separate projects in various stages of advancement including: Bangladesh (two reactors at Rooppur); Belarus (two at Ostrovets – one completed); China (two at Tianwan and two in the Liaoning province); Egypt (four at El Dabaa); Hungary (two at Paks); India (four at Kudankulam); and Turkey (four at Akkuyu).[1525] The Rosatom list also includes a nuclear reactor to be built in Finland, however, as a result of the invasion of Ukraine, the project was cancelled by the consortium in Finland.[1526]

Alexey Likhachev, head of Rosatom, expects that by 2030 up to 70 percent of their revenue will come from outside the country. Likhachev claims that the current order book is worth US$190 billion, of which US$133 billion for projects this decade and US$90 billion on projects already underway.[1527] However, as of mid-2022, WNISR considers of these only nine reactors as recently connected to the grid or under construction: two each in Bangladesh, Belarus and India and three in Turkey, plus Bushehr-2 in Iran—this does not include previously exported reactors, such as those to China (Tianwan-1-4) of those in Central and Eastern Europe. As shown on Figure 9, Russia is the technology supplier of 20 of the 53 reactors under construction as of 1 July 2022, including two in Slovakia completed by a Czech-led consortium.

1521 - *NEI Magazine*, "Russia permanently closes Novovoronezh 3", 4 January 2017, see http://www.neimagazine.com/news/newsrussia-permanently-closes-novovoronezh-3-5709099/, accessed 10 April 2021.

1522 - *NIW*, "Briefs—Russia", *Nuclear Intelligence Weekly*, 3 April 2020.

1523 - IPFM, "BN-800 reactor to fully transition to MOX fuel in 2022", International Panel on Fissile Materials, 9 June 2020, see http://fissilematerials.org/blog/2020/06/bn-800_reactor_to_fully_t.html, accessed 22 May 2021.

1524 - *NEI Magazine*, "BN-800 fast reactor fully loaded with mox fuel", *Nuclear Engineering International*, 23 June 2022, see https://www.neimagazine.com/news/newsbn800-fast-reactor-fully-loaded-with-mox-fuel-9795904, accessed 26 August 2022.

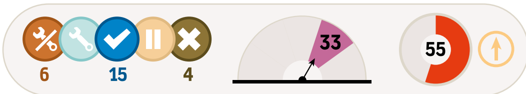
1525 - Rosatom, "Projects", Undated, see https://rosatom.ru/en/investors/projects/, accessed 10 April 2021.

1526 - Fennovoima, "Fennovoima has terminated the contract for the delivery of the Hanhikivi 1 nuclear power plant with Rosatom", Press Release, 2 May 2022.

1527 - *Reuters*, "Russia's nuclear company Rosatom on a drive to sell nuclear technology overseas", as published in *The Moscow Times*, 24 May 2020, see https://www.themoscowtimes.com/2019/06/24/russias-rosatom-sees-foreign-revenues-new-products-fuelling-rapid-growth-a66135, accessed 10 April 2021.

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 that accompanies the deals. The economic sanctions placed upon Russia by the West has and will continue to impact on the nuclear sector. As has been noted, the sale of a reactor to Finland has been scrapped but work on the Paks II reactor in Hungary continues. The sale of nuclear fuel, uranium, has not been the subject of international sanctions although some countries, such as Ukraine, have announced a diversification strategy to totally cease the use of Russia fuel. However, as in the case of the EU and natural gas, a number of countries are heavily dependent on Russian uranium or its fuel services. Russia supplies about a third of all uranium conversion services and 40 percent of enrichment globally. Furthermore, it supplies around a fifth of enrichment to the reactors in the U.S.[1528] While countries are considering what policy measures they could introduce to discourage or ban the purchasing of Russian fuel services, companies are acting unilaterally. Tim Gitzel, the CEO of Cameco, a Canadian uranium company was reported as saying, "it's still early days, but we are seeing what we believe is an unprecedented geopolitical realignment occurring in the nuclear fuel cycle."[1529]

Ukraine



Ukraine has 15 operating reactors, two of the VVER-440 design and the rest VVER-1000s. They provided 81 TWh or 55 percent of power generation in the country in 2021.

The invasion of Ukraine by Russia formally began on the 24 February 2022 but was clearly proceeded by a long and intense period of military buildup and, unreliability of supply of energy to Western Europe, resulting in higher fossil fuel prices. Despite these and clear messaging from the United States of the high likelihood of an imminent invasion, many European Governments appeared to have been taken by surprise.

Twelve out of Ukraine's 15 reactors, that as of July 2022 are officially in operation, were connected to the grid in the 1980s and had an original design lifetime of 30 years. The Zaporizhzhia power plant in the East, which houses six VVER-1000 reactors, was under control of the Russian military (as of mid-September 2022).

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 disbursement of the loan has been gradual, and the third tranche was only made available in 2020.

The nuclear operator has proposed to extend lifetimes of some of the reactors for another 20 years. The proposal was accepted and now constitutes a core element of the nuclear strategy approved by the Government. The country has four closed reactors, all at the Chernobyl nuclear power plant. Three nuclear reactors (two VVER-440s and one VVER-1000) at Rovno

1528 - William Freebairn, "'Disentangling' the global nuclear fuel supply chain after Russia's invasion of Ukraine", *Commodity Insights*, S&P Global, 7 July 2022, see https://www.spglobal.com/commodityinsights/en/market-insights/blogs/electric-power/070722-global-nuclear-fuel-supply-chain-uranium-russia-ukraine-war, accessed 19 July 2022.

1529 - Ibidem.

(also spelled Rivne) have been granted a lifetime extension of 20 years,[1530] as well as three units at South Ukraine and four units at Zaporizhzhia for ten years.[1531,1532]

Two reactors, Khmelnitsky-3 and -4, are officially under construction, but WNISR removed them from the construction list as no active work has been reported in many years. However the Ukrainian Government appears determined to finish them and in September 2020 a Presidential decree instructed the Cabinet to submit a bill on the location, design and construction of the two units, with some suggestions that the total cost of completing Khmelnitsky-3 and -4 in current prices is estimated at UAH 76.8 billion (US$2.8 billion).[1533] It was then reported in August 2020 that nuclear utility Energoatom resumed work on the construction of Khmelnitsky-3 and -4 and promised to approve a plan for completing the units for operation in 2026.[1534] In July 2021, Energoatom set a target of completing all pre-construction activities by 1 October 2021, adding that "Once the Law on KhNPP units 3 and 4 construction is adopted, everything will move very quickly".[1535]

Following the outbreak of the war there has been an increased interest in the purchase of non-Russian reactors. Energoatom announced that in the past few months it had increased the number of reactors that it was interested in purchasing from Westinghouse from five to nine.[1536] The reactors in question would be the AP1000, four of which are operating in China and two are under construction in the U.S., all of which are suffering from cost over-runs and delays – see country reports. Energoatom already has a commercial relationship with Westinghouse, which supplies fuel for 6 VVER 1000s and plans to supply all the reactors and so become independent from Russia.[1537]

Prior to the war proposals were being developed to introduce a direct power line from Khmelnitsky-2 to the European market. The Ukraine-EU Energy Bridge project, with an estimated cost of €243 million (US$290 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

1530 - *NEI Magazine*, "Life extension for Ukraine's Rovno 3", 23 July 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-rovno-3-6258731/, accessed 10 April 2021.

1531 - *NEI Magazine*, "Life extension for Ukraine's Zaporozhye 4", 16 October 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-zaporozhye-4-6803714/, accessed 10 April 2021.

1532 - *NEI Magazine*, "Energoatom marks life extension of Ukraine's Zaporozhye 5 -", 1 February 2021, see https://www.neimagazine.com/news/newsenergoatom-marks-life-extension-of-ukraines-zaporozhye-5-8484622/, accessed 10 April 2021.

1533 - *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/, accessed 10 April 2021.

1534 - *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/, accessed 10 April 2021.

1535 - Energoatom, "Energoatom intensifies works on Khmelnytskyi NPP unit 3 completion", 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 24 July 2021.

1536 - *WNN*, "Ukraine latest: Energoatom looks to future, SNRIU updates EU regulators", 22 June 2022, see https://www.world-nuclear-news.org/Articles/Ukraine-latest-Energoatom-looks-to-future,-SNRIU, accessed 22 June 2022.

1537 - *WNN*, "Energoatom borrows USD51 million to buy extra Westinghouse fuel", 1 June 2022, see https://world-nuclear-news.org/Articles/Energoatom-borrows-USD51-million-to-buy-extra-West, accessed 1 June 2022.

UK-based EDF Trading.[1538] However, on 24 February 2022 Ukraine decoupled its grid from Russia and it operated in isolation until 16 March when it became synchronized to the EU's – work that was expected to have taken a year, was completed in two weeks.[1539]

Impact of War on Nuclear Facilities

Russia invaded Ukraine from a number of directions, from North via Belarus, from the South, through Crimea and from the East through Donestsk and Luhansk. Within days Russia sought to take control of nuclear facilities and in particular the Zaporizhzhia nuclear plant in the East and the Chernobyl facility in the North.

The unprecedented attack on an operating civil nuclear power plant took place on 4 March 2022 with missiles launched at Zaporizhzhia, followed by a military takeover of the facility, including the smashing of administrative buildings, although the Ukrainian staff continue to operate the plant.

The shelling of the station did not result in the release of radiation, but it seems that this is by luck rather than judgement, with various key infrastructure "almost damaged and/or destroyed", according to Olexiy Kovynyevis an independent expert, and former reactor operator and shift supervisor.[1540]

As of 1 July 2022, the IAEA had not been able to visit Zaporizhzhia, and in early July 2022, it was reported that they had, for the second time, lost the remote connection to their safeguards surveillance systems.[1541] (See Nuclear Power and War.)

Russian forces also took control of the Chernobyl site on 24 February 2022 and held it for five weeks before withdrawing on 31 March, and on 19 April 2022 communication between the plant and the Ukrainian regulator was restored.[1542] The IAEA have subsequently been involved in the delivering of equipment and restoring of the safeguards monitoring system. During the Russian control of the facility, external electricity supplies to the plant were entirely lost for four days, which are necessary to maintain the operation of the spent-fuel and waste-management facilities onsite.

1538 - 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, accessed 10 April 2021.

1539 - 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.

1540 - Olexiy Kovynyevis, "Nuclear Safety: Zaporizhzhia and military conflict", *NEI Magazine*, 13 July 2022, see https://neimagazine.com/features/featurenuclear-safety-zaporizhzhia-and-military-conflict-9847710/, accessed 16July 2022.

1541 - *NEI Magazine*, "IAEA loses safeguards connections with Zaporizhzhya NPP and Chernobyl", 1 July 2022, see https://www.neimagazine.com/news/newsiaea-loses-safeguards-connections-with-zaporizhzhya-npp-and-chernobyl-9819101/, accessed 16 July 2022.

1542 - *NEI Magazine*, "Power restored between Chernobyl NPP and Ukraine regulator", 21 April 2022, see https://www.neimagazine.com/news/newspower-restored-between-chernobyl-npp-and-ukraine-regulator-9642650/, accessed 16 July 2022.

ANNEX 2 - STATUS OF NUCLEAR POWER IN THE WORLD

Table 13 – Status of Nuclear Power in the World (as of 1 July 2022)

Country	Nuclear Fleet					Power	Energy
	Operating		LTO	Mean Age[(a)]	Under Construction	Share of Electricity[(b)]	Share of Commercial Primary Energy[(c)]
	Units	Capacity (MW)	Units	Years	Units		
Argentina	3	1 641		31.8	1	7.2% (=)	2.9% (=)
Armenia	1	448		42.5		25.3% (–)	N/A
Bangladesh	-	-		-	2		
Belarus	1	1 110		1.7	1	14.1% (+)	4.7%
Belgium	7	5 942		42.3		50.8% (+)	16.8% (+)
Brazil	2	1 884		31.1		2.4% (=)	1.1% (=)
Bulgaria	2	2 006		32.8		34.6% (–)	N/A
Canada	17	11 929	2	39/39.7		14.3% (=)	6% (=)
China	55	52 070		9	21	5% (=)	2.3% (=)
Czech Republic	6	3 934		31		36.6% (=)	16.6% (=)
Finland	5	4 394		34.7		32.8.% (–)	18.6% (=)
France	56	61 370		37.1	1	69% (+)[(d)]	36.5% (=)
Germany	3	4 055		34		11.9% (=)	4.9% (=)
Hungary	4	1 916		37		46.8% (–)	14.2% (=)
India	19	6 290	3	24.2/20.4	8	3.2% (=)	1.1% (=)
Iran	1	915		10.8	1	1% (=)	0.3% (=)
Japan	10	9 486	23	31.4/34.2	1	7.2% (+)	3.1% (=)
Mexico	2	1 552		30.4		5.3% (=)	1.6% (=)
Netherlands	1	482		49		3.1% (=)	1% (=)
Pakistan	6	3 256		7.6		10.6% (+)	3.7% (+)
Romania	2	1 300		20.5		18.5% (–)	7.3% (=)
Russia	37	27 727		28.9	3	20% (=)	6.4% (=)
Slovakia	4	1 868		30.3	2	52.3% (=)	N/A
Slovenia	1	688		40.7		36.9% (=)	N/A
South Africa	2	1 854		37.6		6% (=)	1.9% (=)
South Korea	24	23 461	1	22.1/21.9	3	28% (–)	11.4% (=)
Spain	7	7 121		37.4		20.8% (–)	9.1% (–)
Sweden	6	6 882		40		30.8% (=)	21% (=)
Switzerland	4	2 960		46.3		30.8% (–)[(e)]	15.6% (–)
Taiwan	3	2 859		38.5		10.8% (–)	5% (–)
Turkey	-	-		-	3		
UAE	2	2 762		1.4	2	1.3%	2.1%
U.K.	11	6 848		37.1	2	14.8% (=)	5.8% (=)
Ukraine	15	13 107		33.4		55% (+)	23.4% (+)
U.S.	92	94 718		41.6	2	19.6% (=)	8% (=)
EU27	**104**	**101 958**		**36.4**	**3**	**25.3% (=)**[(c)]	**11% (=)**
World	**411**	**368 835**	**29**	**31**	**53**	**9.8% (=)**[(c)]	**4.3% (=)**

Sources: WNISR with IAEA-PRIS, BP, 2022, BP, 2022

(a) – Including reactors in LTO/Excluding reactors in LTO.
(b) – Data for 2021, from IAEA-PRIS, “Nuclear Share of Electricity Generation in 2021”, as of July 2022, unless otherwise indicated.
(c) – Data for 2021, “Statistical Review of World Energy”, 2022.
(d) – RTE, “Bilan Électrique 2021”, January 2022.
(e) – Swiss Federal Office of Energy, “Production et Consommation Totales d’Énergie Électrique en Suisse”, 2022.

ANNEX 3 – NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION"

Table 14 – Nuclear Reactors in the World "Under Construction" (as of 1 July 2022)

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
Argentina	**1**	**25**				
Carem25		25	CAREM (PWR)	08/02/2014	2027[1]	yes
Bangladesh	2	2 160				
Rooppur-1		1 080	VVER-1200	30/11/2017	2023[2] (commercial operation)	
Rooppur-2		1 080	VVER-1200	14/07/2018	2024[3] (commercial operation)	
Belarus	**1**	**1 110**				
Belarusian-2		1 110	VVER V-491	03/06/2014	2022[4]	yes
China	**21**	**20 932**				
Changjiang SMR-1		125	ACP-100	13/07/2021[5]	2026[6]	
Changjiang-3		1 000	HPR-1000[7]	31/03/2021	2026[8]	
Changjiang-4		1 000	HPR-1000	28/12/2021[9]	2026[10]	
Fangchenggang-3		1 000	HPR-1000	24/12/2015	2022[11]	yes
Fangchenggang-4		1 000	HPR-1000	23/12/2016	2024[12]	yes
Sanaocun-1		1 117	HPR-1000	31/12/2020	2026[13]	
Sanaocun-2		1 117	HPR-1000	30/12/2021	2027[14]	
Sanmen-3		1 163	CAP-1000	28/06/2022[15]	2027?[16]	
Shidao Bay 1-2[17]		100	HTR-PM	01/12/2012	2022[18]	yes
Shidao-Bay 2-1[19]		1 400	CAP1400	04/2019[20]	2024[21]	
Shidao-Bay 2-2		1 400	CAP1400	11/2019[22]	2024[23]	
Taipingling-1[24]		1 116	HPR-1000	26/12/2019	2025[25]	
Taipingling-2		1 116	HPR-1000	15/10/2020	2026[26]	
Tianwan-7		1 171	VVER V-491	19/05/2021	2026[27]	
Tianwan-8		1 171	VVER V-491	15/02/2022	2027[28]	
Xiapu-1		642	CFR-600	29/12/2017	2023[29] (commercial operation)	
Xiapu-2		642	CFR-600	27/12/2020[30]	2026?[31]	
Xudabu-3[32]		1 200	VVER V-491	19/05/2021	2027[33]	
Xudabu-4		1 200	VVER V-491	19/05/2022	2028[34]	
Zhangzhou-1		1 126	HPR-1000	16/10/2019	2024[35]	
Zhangzhou-2		1 126	HPR-1000	04/09/2020	2025[36]	

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
France	**1**	**1 630**				
Flamanville-3		1 630	EPR	03/12/2007	2023[37]	yes
India	**8**	**6 028**				
Kakrapar-4		630	PHWR-700	22/11/2010	2024[38]	yes
Kudankulam-3		917	VVER V-412	29/06/2017	2024[39]	yes
Kudankulam-4		917	VVER V-412	23/10/2017	2025[40]	yes
Kudankulam-5		917	VVER V-412	29/06/2021	2026/2027[41]	likely[42]
Kudankulam-6		917	VVER V-412	20/12/2021	2027[43]	likely[44]
PFBR		470	FBR	23/10/2004	9/2024[45]	yes
Rajasthan-7		630	PHWR	18/07/2011	06/2023[46]	yes
Rajasthan-8		630	PHWR	30/09/2011	12/2023[47] (commissioning)	yes
Iran	**1**	**974**				
Bushehr-2		974	VVER V-446	02/1976[48]	2024[49]	yes
Japan	**1**	**1 325**				
Shimane-3		1 325	ABWR	12/10/2007	2025?[50]	yes
Russia	**3**	**2 650**				
BREST-OD-300		300	FBR	08/06/2021	2026[51]	
Kursk 2-1		1 175	VVER V-510	29/04/2018	2023[52] (commissioning)	
Kursk 2-2		1 175	VVER V-510	15/04/2019	2024[53] (commissioning)	
Slovakia	**2**	**880**				
Mochovce-3		440	VVER V-213	01/01/1985	2022[54]	yes
Mochovce-4		440	VVER V-213	01/01/1985	2023[55]	yes
South Korea	**3**	**4 020**				
Shin-Hanul-2		1 340	APR-1400	19/06/2013	7/2023[56] (commercial operation)	yes
Shin-Kori-5		1 340	APR-1400	03/04/2017	03/2024[57] (commercial operation)	yes
Shin-Kori-6		1 340	APR-1400	20/09/2018	03/2025[58] (commercial operation)	yes
Turkey	**3**	**3 342**				
Akkuyu-1		1 114	VVER V-509	03/04/2018	2024[59]	yes
Akkuyu-2		1 114	VVER V-509	08/4/2020	2025[60]	
Akkuyu-3		1 114	VVER V-509	10/03/2021	2026[61]	
UAE	**2**	**2 690**				
Barakah-3		1 345	APR-1400	24/09/2014	2023[62]	yes
Barakah-4		1 345	APR-1400	30/07/2015	2023[63]	yes

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
U.K.	**2**	**3 260**				
Hinkley Point C-1	1	1 630	EPR-1750	11/12/201864	2027[65]	yes
Hinkley Point C-2	1	1 630	EPR-1750	12/12/2019[66]	2028[67]	yes
U.S.	**2**	**2 234**				
Vogtle-3		1 117	AP-1000	12/03/2013	2023[68]	yes
Vogtle-4		1 117	AP-1000	19/11/2013	2023[69]	yes
World	**53**	**53 260**		**1976–2022**	**2022–2028**	**26**

1 - Further delayed. The construction of CAREM, suspended in 2019 "due to breaches by contractor companies", was expected to restart in May 2020, with no indication about the impact this would have on the project's timeline.
See *NEI Magazine*, "Work resumes on nuclear projects in Argentina", 23 April 2020, see https://www.neimagazine.com/news/newswork-resumes-on-nuclear-projects-in-argentina-7887154, accessed 30 July 2020.

In July 2021, CNA announced that NA-SA had been contracted to complete the reactor, and that "this new contract establishes a duration of 36 months to complete the reactor building".
See CNEA, "CNEA y la empresa NA-SA firman un contrato para completar la construcción del CAREM", Press Release (in Spanish), 5 July 2021, see https://www.argentina.gob.ar/noticias/cnea-y-la-empresa-na-sa-firman-un-contrato-para-completar-la-construccion-del-carem, accessed 8 July 2021.

According to CAREM's project manager, concreting restarted in January 2022, and startup is expected in 2027.
See Matías Alonso, "Sol Pedre: 'El CAREM es un salto cualitativo para el sector nuclear argentino'", *Agencia TSS* (in Spanish), 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.

2 - Expected startup at construction start.
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.

There is concern about the implications of the financial sanctions on Russia, although Rosatom says "it does not see disruption in any of the commitments and work schedules in the project."
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.

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. See previous note.

4 - Delayed. Originally expected in 2020, startup of Belarusian-2 is now expected in 2022; fuel loading took place in December 2021.
See Rosatom, "Fuel loading has started at Belarus NPP Unit 2", Press Release, 22 December 2021, see https://www.rosatom-europe.com/press-centre/news/fuel-loading-has-started-at-belarus-npp-unit-2/, accessed 8 August 2022.

5 - CNNC, "World's first commercial Linglong One onshore small reactor starts construction", Press Release, 14 July 2021, see https://en.cnnc.com.cn/2021-07/14/c_642603.htm, accessed 31 August 2021.

6 - No official startup date as of construction start. According to *World Nuclear News* (*WNN*), "Construction time is expected to be 58 months".
See *WNN*, "China starts construction of demonstration SMR", 13 July 2021, see https://www.world-nuclear-news.org/Articles/China-starts-construction-of-demonstration-SMR, accessed 16 July 2021.

7 - The HPR-1000 also goes by the name Hualong One.

8 - 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.

9 - China Huaneng Group Co., "华能海南昌江核电二期工程4号机组开工" ["Unit 4 of Huaneng Hainan Changjiang Nuclear Power Phase II Project started construction"], 29 December 2021 (in Chinese), see https://www.chng.com.cn/detail_jtyw/-/article/ccgb60va5Gwc/v/988775.html, accessed 22 August 2022.

10 - *WNN*, "Construction begins at second Changjiang Hualong One", 29 December 2021, see https://world-nuclear-news.org/Articles/Construction-begins-at-second-Changjiang-Hualong-O, accessed 30 December 2021.

11 - Delayed. In January 2022, CGN adjusted the expected date of commencement of operation of Fangchenggang Unit 3 to the second half of 2022, a delay of a few months compared to original announcements.
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.

Although CGN's Annual Reports referred to 2022 as "Expected Date of Commencement of Operation", based on information from sources in China, WNISR had used 2021 as expected startup date.

12 - 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, op. cit.

13 - Commencement of operation of Sanaocun-1 (also known as San'ao or Cangnan-1) is expected in 2026.
See CGN Power, "Annual Report 2020", April 2021, see http://en.cgnp.com.cn/encgnp/c100882/2021-04/08/c95f2296e95a4aab8a1d7b749996bb43/files/72fd1f144fa44cefba5496fb45eaaab6.pdf, accessed 1 June 2021.

14 - Construction of Sanaocun-2 (also known as San'ao or Cangnan-2) started in December 2021 with expected commencement of operation in 2027. See CGN Power, "2021 Annual Report", 2022, see http://en.cgnp.com.cn/encgnp/c100882/2022-04/07/c458fe3cfd6e4e93950b586f499ce402/files/8787336618b24d2090d0ea5e9e1554d6.pdf, accessed 7 April 2022.

15 - CNNC, "CNNC Sanmen nuclear power plant starts construction on second phase project", China National Nuclear Corporation, Press Release, 29 June 2022, see https://en.cnnc.com.cn/2022-06/29/c_785202.htm, accessed 30 June 2022.

16 - 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 July 2022, see https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx, accessed 8 August 2022.

17 - IAEA-PRIS reports the twin High Temperature Reactors (HTR-PM) at the Shidao Bay site plant as consisting of one 200-MW unit. Accordingly, in previous WNISR editions, Shidao Bay-1 has been accounted for as one unit. However, Shidao Bay-1 (also called Shidaowan-1) actually consists of two 100-MW reactors, and consequently, as of WNISR2020, they are considered as two units (Shidao Bay 1-1 and 1-2).
See CNEA, "Key components of second HTR-PM reactor connected", n.d., see http://en.china-nea.cn/site/content/176.html, accessed 10 May 2020.

18 - Repeatedly delayed. Grid connection of the first unit of the twin reactors (see previous note) officially took place on 20 December 2021. See WNN, "Demonstration HTR-PM connected to grid", 21 December 2021, see https://www.world-nuclear-news.org/Articles/Demonstration-HTR-PM-connected-to-grid, accessed 22 August 2022. There is no information on connection of the second unit. WNISR2022 considers it as under construction.

19 - 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 them as "under construction" on the basis of the Chinese National Nuclear Safety Administration (NNSA) map as of June 2019.
See *NIW*, "Chinese Power Reactor Project Wrapped in Secrecy", 12 July 2019.

20 - 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*, 20 December 2019. See previous note.

21 - 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. WNISR2022 uses 2024 as expected grid connection.

22 - According to sources in China, first basemat concrete for the second CAP1400 reactor was poured in November 2019. See previous notes.

23 - No official startup dates at this point. WNISR2022 uses 2024 for grid connection date. See previous notes.

24 - Also known as Huizhou.

25 - CGN Power, "Annual Report 2019", April 2020, see http://en.cgnp.com.cn/encgnp/c100882/202004/f3c20533b65c4cf3a41583190c02057c/files/a5bc0c2ac79c425398a2296b2b054005.pdf, accessed 2 April 2020.

26 - CGN Power, "Annual Report 2021", 2022, op. cit. (Changed from 2025 in WNISR2020).

27 - 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".
Rosatom, "Start of new unit construction at China's Tianwan and Xudapu nuclear power plants", Press Release, 19 May 2021, see https://rusatom-overseas.com/media/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants.html, 19 August 2022.

28 - See Rosatom State Corporation Engineering Division, "The First Concrete has been Laid at Tianwan NPP Power Unit 8 in China", 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.

29 - *WNN*, "China begins building pilot fast reactor", 29 December 2017, see http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html, accessed 30 December 2017.

30 - Not listed in IAEA-PRIS. *NEI*, "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.

31 - No official information about construction start/expected grid connection. WNISR2022 uses 2026 (same duration as Xiapu-1).

32 - Also known as Xudapu or Xudabao.

33 - 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 and https://rusatom-overseas.com/media/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants.html, accessed 19 August 2022.

34 - 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.

35 - 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.

36 - No official startup date at construction start.
See *WNN*, "Zhangzhou unit 2 construction starts", 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.

37 - Further delayed. Delayed many times from its original planned startup date of 2012. In January 2022, EDF announced a new provisional date for fuel loading: by the second quarter of 2023 (compared to end of 2022 in WNISR2021). Startup of the reactors is still expected in 2023. See EDF, "Update on the Flamanville EPR", Press Release, 12 January 2022, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/update-on-the-flamanville-epr, accessed 12 January 2022.

38 - Further delayed (over a year compared to WNISR2021). 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 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.

39 - Delayed. In 2021, *Nuclear Intelligence Weekly* (*NIW*) reported that "Units 3 and 4 … will now be completed in September 2024 and March 2025, respectively, according to a government document."
See Rakesh Sharma, "Kudankulam-5 Construction Start Marks New Milestone", *Nuclear Intelligence Weekly*, 2 July 2021. See also note on Kudankulam-5. NPCIL keeps March 2023 as Expected date of Commercial Operation.

40 - Delayed. See previous note. NPCIL keeps November 2023 as Expected date of Commercial Operation.

41 - The expected construction duration of Kudankulam-5 is 66 months.
See Lok Sabha, "Unstarred Question No.2756: Kudankulam Nuclear Power Plant", Department of Atomic Energy, Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 10 March 2021, see https://dae.gov.in/writereaddata/lsusq%202756.pdf, accessed 30 June 2021.

42 - 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 Shri Abir Ranjan Biswas, "Unstarred Question No. 3286: Status of Work at Kudankulam Power Plant", Rajya Sabha, Department of Atomic Energy, Government of India, Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions, and Prime Minister's Office, see http://dae.gov.in/writereaddata/rsusq3286.pdf, accessed 7 April 2022.

43 - The expected construction duration of Kudankulam-6 is 75 months.
See Lok Sabha, "Unstarred Question No.2756: Kudankulam Nuclear Power Plant", Department of Atomic Energy, Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 10 March 2021.

44 - See note on Kudankulam-5.
See Rajya Sabha, "Unstarred Question No. 3286: Status of Work at Kudankulam Power Plant", Government of India, March 2022, op. cit.

45 - Further delayed. Expected operation pushed back from October 2022 to September 2024.
MoSPI, "440th Flash Report on Central Sector Projects (Rs.150 crore and above) - July 2022", Ministry of Statistics and Programme Implementation, 2022, see http://www.cspm.gov.in/english/flr/FR_July_2022.pdf, accessed 27 August 2022.

46 - Further delayed (over a year compared to WNISR2021). As of July 2022, the "Expected Date of Commercial Operation" is "under review" on NPCIL's dedicated webpage, while the Central Electricity Regulatory Commission approved a petition from NPCIL that anticipates Rajasthan-7 being synchronized with the grid only by June 2023.
See Shri P.K.Pujari et al., "Petition No. 112/MP/2022", Central Electricity Regulator Commission, April 2022, see https://cercind.gov.in/2022/orders/112-MP-2022.pdf, accessed 24 May 2022.

47 - Further delayed (at least 9 months since WNISR2021). According to Ministry of Statistics and Programme Implementation (MoSPI) commissioning is now expected in December 2023 (compared to March 2023 one year earlier).
See MoSPI, "435th Flash Report on Central Sector Projects (Rs.150 crore and above) – February 2022", February 2022, see http://www.cspm.gov.in/english/images/FR_Feb_2022.pdf, accessed 6 April 2022.

48 - 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.

49 - 2024 is the date announced when construction resumed. However, as of June 2022, NEI mentions a 28-month delay on the Busherhr-2 and -3, 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", Nuclear Engineering International, 28 June 2022, see https://www.neimagazine.com/news/newsiran-begins-concrete-pouring-for-wall-at-bushehr-2-9806133, accessed 7 July 2022.

50 - Construction status unclear. 2025 used for WNISR projections.

51 - Rosatom, "ROSATOM starts construction of unique power unit with BREST-OD-300 fast neutron reactor", 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.

52 - WNISR previously used 2022, also quoted in numerous documents.
See Rosatom, "Rosatom Newsletter #202—Kursk II Passed Construction Milestone", December 2017, see https://rosatomnewsletter.com/2017/12/28/kursk-ii-passed-construction-milestone/, accessed 13 April 2022.

53 - See previous note.

54 - Further delayed since WNISR2021. According to the latest update by Škoda, "The start-up of Unit 3 is currently scheduled to take place at the end of 2022, while the start-up of Unit 4 is planned in 2024."
See ŠKODA JS, "Units 3 and 4 at Mochovce NPP, Slovakia", n.d. see https://www.skoda-js.cz/reference/nuclear-powerplant-mochovce/, accessed 17 August 2022.

55 - Further delayed. See previous note.

56 - Further delayed. As of July 2022, Commercial operation is expected in July 2023 (compared to March 2023 in WNISR2021).
See KHNP, "Nuclear Power Construction—Shin-Hanul #1,2", Various Dates, see https://cms.khnp.co.kr/eng/contents.do?key=524, last accessed 9 August 2022.

57 - Further delayed. Construction officially started in April 2017, suspended in July to resume October of the same year. Commercial operation at construction start was October 2021; after numerous delays, it is now expected in March 2024 (as anticipated in WNISR2021). See KHNP, "Nuclear Power Construction – Shin-Kori #5,6", various dates, see https://cms.khnp.co.kr/eng/contents.do?key=525, last accessed 9 August 2022.

58 - Further delayed. As anticipated in WNISR2021, commercial operation has been pushed back to March 2025.
See KHNP, "Nuclear Power Construction—Shin-Kori #5,6", various dates, see https://cms.khnp.co.kr/eng/contents.do?key=525, last accessed 9 August 2022.

59 - Delayed. The Akkuyu reactors are officially to be completed one per year starting in 2023.
See *WNN*, "Akkuyu construction to be completed by 2026, says project CEO : New Nuclear", 10 February 2021, see https://www.world-nuclear-news.org/Articles/Akkuyu-fully-operational-by-2026,-says-project?feed=feed, accessed 10 April 2021.
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.

60 - Official startup date is often quoted as 2024, but WNISR2021 uses a 5-year construction period.
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.

61 - The Akkuyu reactors are officially to be completed one per year starting in 2023.
See *WNN*, "Akkuyu construction to be completed by 2026, says project CEO : New Nuclear", 10 February 2021, see https://www.world-nuclear-news.org/Articles/Akkuyu-fully-operational-by-2026,-says-project, accessed 10 April 2021.
However, WNISR2021 keeps a 5-year construction time, and a one-per-year startup frequency, beginning with Akkuyu-1 in 2024.

62 - Further delayed. In November 2021, ENEC announced the "construction completion" of Barakah-3, with electricity production scheduled in 2023. Operating license was granted in June 2022, followed by fuel loading.
See ENEC, "Fuel Assemblies loading started at Unit 3 of the Barakah Plant after Received Operating License from FANR", Press Release, 19 June 2022, see https://www.enec.gov.ae/news/latest-news/fuel-assemblies-loading-started-at-unit-3-of-barakah-plant-after-receiving-operating-license/, accessed 19 June 2022.

63 - Delayed. Although startup of Barakah-3 is now expected in 2023, there is no indication of a new delay for Barakah-4.

64 - 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.

65 - Further delayed. 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".
See EDF, "Hinkley Point C Update", Press Release, 19 May 2022, see https://www.edf.fr/sites/groupe/files/epresspack/3081/ccb6205433272bb0cbfac560cea3b537.pdf, accessed 19 May 2022.

66 - 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.

67 - Further delayed. 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". However, no precise date was provided at construction start, nor new provisional date.
See EDF, "Hinkley Point C Update", Press Release, 19 May 2022, op. cit.

68 - Further delayed. As of July 2022, Vogtle Unit 3 is expected to be in service by the end of the first quarter of 2023, compared to second quarter of 2022 in WNISR2021.
See Scott DiSavino, "Southern delays startup of new Georgia nuclear reactors, boosts costs", *Reuters*, 17 February 2022, see https://www.reuters.com/business/energy/southern-delays-startup-new-georgia-nuclear-reactors-boosts-costs-2022-02-17/, accessed 19 February 2022.

69 - Further delayed. As of July 2022, Vogtle unit 4 is expected to be in service by the end of the fourth quarter of 2023, compared to first quarter of 2023 in WNISR2021.
See Scott DiSavino, "Southern delays startup of new Georgia nuclear reactors, boosts costs", *Reuters*, 17 February 2022, op. cit.

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
Bq/kg	Becquerel per kilogram
Bq/L	Becquerel per liter
mSv	millisievert
Sv	Sievert

ACRONYMS

3/11	"Great East Japan Earthquake"; beginning of the Fukushima nuclear disaster (11 March 2011)
ABB	Asea Brown Boveri (Multinational Corporation, Sweden and Switzerland)
ABWR	Advanced Boiling Water Reactor (Reactor design)
AEA	Atomic Energy Act (United States)
AEOI	Atomic Energy Organization of Iran
AGR	Advanced Gas-cooled Reactor (Reactor design)
AHWR	Advanced Heavy Water Reactor (Reactor design)
ALPS	Advanced Liquid Processing Systems
APR	Advanced Pressurized Water Reactors (Reactor type)
ARA	Advanced Reactor for Multipurpose Research Applications
ASLB	Atomic Safety Licensing Board (U.S. Nuclear Regulatory Commission)
ASN	*Autorité de Sûreté Nucléaire* – Nuclear Safety Authority (France)
BBO	Build-Own-Operate
BEIS	Department for Business, Energy & Industrial Strategy
BWR	Boiling Water Reactor (Reactor design)
CANDU	CANadian Deuterium Uranium (Reactor design, Canada)
CAREM	*Central Argentina de Elementos Modulares* – Small Modular PWR Design (under construction in/by Argentina)
CEA	*Commissariat à l'énergie atomique et aux énergies alternatives* – Alternative Energies and Atomic Energy Commission (France) or Central Electricity Authority (India)
CEFR	China Experimental Fast Reactor
ČEZ	*České Energetické Závody* (state-owned energy Utility, Czech Republic)
CfD	Contract for Difference
CFE	*Comisión Federal de Electricidad* (state-owned utility, Mexico)

CGN	China General Nuclear Power Corporation
CNAAA	Central Nuclear Almirante Alvaro Alberto (Nuclear plant, Brazil)
CNEA	*Comisión Nacional de Energía Atómica* – National Atomic Energy Commission (Argentina)
CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
ComEd	Commonwealth Edison (Exelon subsidiary, United States)
CPUC	California Public Utilities Commission (United States)
CSIR	Council for Scientific and Industrial Research (South Africa)
CSN	Consejo de Seguridad Nuclear – Nuclear Safety Council (Spain)
EDF	*Électricité de France* – Power Utility (France)
EIA	Environmental Impact Assessment or Energy Information Administration (U.S. Department of Energy)
ENEC	Emirates Nuclear Energy Corporation
ENRRA	Egyptian Nuclear and Radiological Regulatory Authority
ENSI	*Eidgenössisches Nuklearsicherheitsinspektorat* – Federal Nuclear Safety Inspectorate (Switzerland)
EPR	European Pressurized Water Reactor (Reactor Design)
EPZ	*Elektriciteits Produktiemaatschappij Zuid-Nederland* (Power Utility, Netherlands)
ESBWR	Economic Simplified Boiling Water Reactor (Reactor design)
EU	European Union
FANC	*Federaal Agentschap voor Nucleaire Controle* – Federal Agency for Nuclear Control (Belgium)
FERC	Federal Energy Regulatory Commission (United States)
FID	Final Investment Decision
FL3	Flamanville-3 (Reactor, France)
FOAK	First-Of-A-Kind
FY	Financial Year
GDA	Generic Design Assessment
HALEU	High-Assay Low-Enriched Uranium
HAEA	Hungarian Atomic Energy Authority
HB6	House Bill 6 (State legislation, United States)
HFT	Hot Functional Test
HPC	Hinkley Point C (Reactor, United Kingdom)
HTGR	High Temperature Gas Cooled Reactor
HTR	High Temperature (Gas-Cooled) 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 (Federal legislation, United States)
IRA	Inflation Reduction Act (Federal legislation, United States)
IRENA	International Renewable Energy Agency
IRRS	Integrated Regulatory Review Service (of the International Atomic Energy Association)
JAEA	Japan Atomic Energy Agency
JAEC	Jordan Atomic Energy Commission
JAIF	Japan Atomic Industrial Forum
KA-CARE	King Abdullah City for Atomic and Renewable Energy (Saudi Arabia)

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)
KhNPP	Kudankulam Nuclear Power Project (India)
KNPP	Kazakhstan Nuclear Power Plants
LTE	Long-Term Enclosure
LTO	Long-Term Outage
LTS	Long-term Shutdown
MEAG	Municipal Electric Authority of Georgia (Company, United States)
METI	Ministry of Economy, Trade and Industry (Japan)
MITECO	Ministry for Ecological Transition and Demographic Challenge
MOPR	minimum offer price rule
MoU	Memorandum of Understanding
MOX	Mixed Oxide Fuel
NA-SA	*Nucleoeléctrica Argentina SA* (state-owned utility, Argentina)
NDC	Nationally Determined Contribution
NEA	National Energy Administration (China)
NEK	*Nuklearna Elektrarna Krško* (operator of Krško plant, governed by Slovenia and Croatia)
NNR	National Nuclear Regulator (South Africa)
NPCIL	Nuclear Power Corporation of India
NPP	Nuclear Power Plant
NPPA	Nuclear Power Plants Authority (Egypt)
NRA	Nuclear Regulation Authority (Japan)
NRC	Nuclear Regulatory Commission (United States)
NSSC	Nuclear Safety and Security Commission (South Korea)
OL3	Olkiluoto-3 (Reactor, Finland)
ONR	Office for Nuclear Regulation (United Kingdom)
PAEC	Pakistan Atomic Energy Commission
PEJ	*Polskie Elektrownie Jadrowe* (Power Company, Poland)
PFBR	Prototype Fast Breeder Reactor (Reactor, India)
PG&E	Pacific Gas & Electric (Utility, United States)
PLEX	Plant Life Extension
PRIS	Power Reactor Information System (of the International Atomic Energy Agency)
PSC	Public Service Commission
PSEG	Public Service Enterprise Group
PUCO	Public Utilities Commission of Ohio (United States)
PWR	Pressurized Water Reactor (Reactor type)
PZEM	*Provinciale Zeeuwsche Electriciteits-Maatschappij* (Power Utility, Netherlands)
R&D	Research and Development
RAB	Regular Asset Base
RD&D	Research, Development and Demonstration
RGGI	Regional Greenhouse Gas Initiative

RTE	*Réseau de Transport d'Électricité* – Transmission System Operator (France)
SALTO	Safety Aspects of Long Term Operation
SMART	System-Integrated Modular Advanced Reactor
SMR	Small Modular Reactor
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SPD	*Sozialdemokratische Partei* – Social Democrat Party (Germany)
SÚJB	*Státní úřad pro jadernou bezpečnost* — State Office for Nuclear Safety (Czech Republic)
TEPCO	Tokyo Electric Power Company (Japan)
U.K.	United Kingdom
U.S.	United States of America
U.S.NRC	U.S. Nuclear Regulatory Commission
UAE	United Arab Emirates
UAMPS	Utah Associated Municipal Power Systems (United States)
UNFCCC	United Nations Framework Convention on Climate Change
VD	*Visite Décennale* – Decennial Safety Review (France)
VVER	*Vodo-Vodianoï Energuetitcheski Reaktor* – Russian Pressurized Water Reactor Designs
WNA	World Nuclear Association
WNISR	World Nuclear Industry Status Report
ZEC	Zero Emission Credits
ZNPP	Zaporizhzya Nuclear Power Plant (Ukraine)

ANNEX 5 – ABOUT THE AUTHORS

Antony Froggatt joined Chatham House in 2007 where he is Senior Research Fellow and Deputy-Director of the Environment and Society Programme. 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.

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.

M.V. Ramana is the Simons Chair in Disarmament, Global and Human Security and Professor at the School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada. He received his Ph.D. in theoretical physics from Boston University. Ramana is the author of "The Power of Promise: Examining Nuclear Energy in India" (*Penguin Books*, 2012) and co-editor of "Prisoners of the Nuclear Dream" (*Orient Longman*, 2003). He is a member of the International Panel on Fissile Materials (IPFM), the International Nuclear Risk Assessment Group (INRAG) and the Canadian Pugwash Group. He is the recipient of a Guggenheim Fellowship and a Leo Szilard Award from the American Physical Society.

Michael Sailer is an independent consultant on nuclear energy. He has more than 40 years of experience in the field, most notably regarding the safety of nuclear power plants and other nuclear facilities, the storage and final disposal of nuclear and other radioactive wastes. He holds a degree in chemical engineering (Dipl.-Ing.) from the Technical University Darmstadt, Germany. Between 2009 and his retirement in August 2019, he was CEO of Oeko-Institut e.V. Previously, 1983–2009, he was heading Oeko-Institut's Nuclear Engineering and Facility Safety Division. From 2008 to 2019, he was Chairman of the Nuclear Waste Management Commission (ESK), which advises the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). From 1999 to 2014, he was member of the Reactor Safety Commission (RSK) of the German Environment Ministry and RSK's chairman from March 2002 to March 2006. From 2012 to 2019, he was also a member of the Expert Group on Reactor Safety (ERS) of the Swiss Federal Nuclear Safety Inspectorate (ENSI).

Mycle Schneider is an independent international analyst on energy and nuclear policy based in Paris. He is the Coordinator and Publisher of the World Nuclear Industry Status Reports (WNISR). He is a founding board member of the International Energy Advisory Council (IEAC) and served as the Coordinator of the Seoul International Energy Advisory Council (SIEAC). He is a member of the International Panel on Fissile Materials (IPFM), based at Princeton University, the International Nuclear Security Forum (INSF), both in the U.S, and the International Nuclear Risk Assessment Group (INRAG), Austria. He provided information and consulting services, amongst others, to the Austrian Ministry for Climate Action, Environment, Energy, the Belgian Energy Minister, the French and German Environment Ministries, the U.S. Agency for International Development, the International Atomic Energy Agency (IAEA), the European Commission, and the French Institute for Radiation Protection and Nuclear Safety (IRSN). Schneider has given evidence and held briefings at national Parliaments in 16 countries and at the European Parliament. He has given lectures at over 20 universities and engineering schools around the globe.

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.

Agnès Stienne is an artist, cartographer, and independent graphic designer. She has worked for a decade to the French journal *Le Monde Diplomatique*, and the Visioncarto.net website dedicated to cartographical experimentation. She has created numerous "narrative cartographics" to illustrate a wide range of complex subjects and issues. The results of her research are featured on the Visioncarto.net website, as "geo-poetic" briefs, in which she uses aquarelle-paint to translate her findings into maps and data-visualizations. In 2021, she published "Inside the nebula of the Bill & Melinda Gates Foundation", a series of visualizations of the Foundation's 2017 funding and donations. For several years, she has been leading a research project focusing on agricultural practices, "land grabbing" and other fundamental agricultural and food related issues. Among her latest works set in continuity with her pieces on the "Geography of the oil palm", she created a series of paintings based on satellite images from Google Earth, which were exhibited along with her works "Geopoetics of Fields" ("Géopoétique des champs") in Le Mans (France) in October 2020, February 2021 and January 2022.

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).

Aviel Verbruggen is Prof. emeritus at Antwerp University, Belgium. He is a multi-disciplinary engineering-economics-politics scholar on environmental and energy topics, e.g., electricity (nuclear power, cogeneration, markets, pricing), renewable energy support, emissions trading, policy planning, political economy of energy transformations. He has been a contributor to the Intergovernmental Panel on Climate Change (IPCC) between 1998 and 2014, mainly to the Special Report on Renewable Energy (2008–2011). For more information see www.avielverbruggen.be.

Alexander James Wimmers is a research associate in the AT-OM research group at the Workgroup for Economic and Infrastructure Policy (WIP) at the Berlin University of Technology (TU Berlin), Germany. Before joining WIP, he worked as a consultant for renewable energy markets at a renowned energy consulting firm in Berlin. He holds an MSc in Business Administration and Engineering (Wirtschaftsingenieurwesen) from RWTH Aachen University. His current research focuses on the political economy of nuclear power, from new build, operation, decommissioning and nuclear waste management. He is a member of a long-term research project on nuclear decommissioning in cooperation with the University of Basel.