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The World Nuclear Industry
Status Report 2020

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The World Nuclear Industry Status Report 2020

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ACKNOWLEDGMENTS

A difficult year. For so many people around the globe. Everything seems to be slower, needing more effort, as our attention and energy is often deviated towards statistics on COVID-19 cases, deaths and combat strategies. Behind the numbers are people. It is not only that the many human lives were lost, it is also many people that contracted the illness that have to cope with long-term health effects. Not to talk about the devastating social effects, many of which are yet to unfold.

The project coordinator is therefore particularly thankful to everyone who made the production of this year's report possible, the authors and data-manager, the designers and artists, the webmaster and all the supporters.

As for so many years now, a big thank you to Antony Froggatt for his conceptual ideas, his contributions, his reactivity and his friendship.

At the core of the *World Nuclear Industry Status Report* (*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 two years. As ever, no WNISR without her. Thanks so much.

The WNISR project can solidly count on the regular, reliable, professional and insightful contributions from M.V. Ramana, Tadahiro Katsuta and Ben Wealer. Many thanks to all of you.

WNISR2020 greatly profits from a wonderful new contributing author, Ali Ahmad. We are very grateful for his excellent input.

We were lucky to have two outstanding top nuclear policy experts, Frank von Hippel and Jungmin Kang, providing a generous, lucid foreword that puts the WNISR work into broader context. Thanks a million.

Many other people have contributed pieces of work to make this project possible and to bring it to the current standard. In particular Shaun Burnie, whose multiple contributions again have been invaluable and are highly appreciated. Thank you also to Caroline Peachey, *Nuclear Engineering International*, for providing the load factor figures quoted throughout the report.

Artist and graphic designer Agnès Stienne created the redesigned layout in 2017 and is constantly improving our graphic illustrations that get a lot of praise around the world. Thank you.

Nina Schneider put her meticulous proof-reading and production skills to work again and added some helpful research. Thanks so much.

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

For the second time, we owe the idea, design, and realization of the cover to renowned German painter Friedhelm Meinass, and designer Constantin E. Breuer, ("who congenially implements his ideas") and who have also contributed the acclaimed original artwork for the WNISR2019 cover. Thanks so much for this brilliant, thoughtful and very generous contribution.

This work has greatly benefitted from additional proofreading by Walt Patterson, partial proof-reading, editing suggestions, comments or other input by Pinar Demircan, Anton Eberhard, Jan Haverkamp, Christian von Hirschhausen, Gregory Jaczko, Daul Jang, Lutz Mez, Olexi Pasyuk, Steve Thomas, and others. Thank you all.

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NOTE

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

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FOREWORD

By Frank von Hippel & Jungmin Kang[1]

The World Nuclear Industry Status Report (*WNISR*) has become an invaluable resource for those interested in trends in nuclear power globally and in a more detailed understanding of developments in particular countries.

As this report makes clear, globally, nuclear power continues to be in stasis. In Western Europe and the United States (U.S.), the rate of retirements is increasing while the few new construction projects have had catastrophic cost overruns and schedule slippages.

In the U.S., Westinghouse – once the world's leading designer of nuclear power plants – went bankrupt in 2017 as a result of the huge cost overruns and schedule delays that resulted in the termination of construction on two AP1000 reactors in South Carolina and a continuing controversy over the construction of another two in Georgia. These fiascos have foreclosed for the foreseeable future construction of new conventional 1000+ MWe nuclear power plants in the United States.

After providing loan guarantees totaling US$12 billion for the Georgia plant, the U.S. Department of Energy, has pivoted to support the development of a variety of "small modular reactors" (SMRs) with individual unit outputs ranging from tens to hundreds of megawatts. A few may be bought by the government to provide power to large government installations such as army and navy bases and national nuclear laboratories but, as WNISR2020 concludes, "there is no need to wait with bated breath for SMRs to be deployed" on a large scale.

In Japan, almost a decade after the Fukushima accident, nuclear utilities continue to struggle to meet the new regulatory requirements – typically pouring more than one billion dollars into safety upgrades per reactor while struggling to reassure host communities and prefectures.

China continues to grow its nuclear capacity but at a slowing rate and Russia's government continues to finance Rosatom's aggressive export of nuclear power plants to new nuclear countries.

In South Korea, as in China, the cost of constructing new nuclear power plants has been kept under better control than in West Europe and the United States. The Fukushima accidents and falsification of safety certificates in South Korea's nuclear industry turned a large fraction of the population against nuclear power, however, and the Moon Administration banned the construction of new nuclear power plants after Shin Kori-6.[2] New nuclear power plant construction could find a more sympathetic ear in the Blue House[3], however, if the conservatives come back to power in the presidential election of 2022.

Under a US$20 billion deal with the United Arab Emirates (UAE), four South Korean-designed APR1400 reactors are being built at Barakah by a consortium led by the Korea Electric Power

1 - Jungmin Kang is South Korea's member of the International Panel on Fissile Materials and was, during 2018, the Chairman of the Korea Nuclear Safety and Security Commission.

Frank N. von Hippel is a Senior Research Physicist and Professor of Public and International Affairs emeritus at Princeton University's Program on Science and Global Security.

2 - Editor's Note: Four units remain under construction in South Korea. Shin-Kori-6 is the last one scheduled to start up, in 2024.

3 - Editor's Note: The Blue House is the official residence of the President of the Republic of Korea.

Corporation. The project has not gone smoothly, however. Barakah-1 began feeding power into UAE's grid in August 2020, three years later than originally projected and concrete "voids" and "cracks" were found in the containment buildings of Unit 2 and Unit 3 in 2018.[4] As described in WNISR2020, similar faults of containment buildings have raised significant safety issues for a number of nuclear power plants in South Korea. In part, these defects reflect inadequate inspections by safety regulators when the containments were built. China, which is still developing its nuclear regulatory regime, should take note.

UAE's long-term energy plan does not include any additional nuclear capacity, at least before 2050. South Korea is cooperating on nuclear energy with Saudi Arabia but, will not be able to sell APR1400s there unless Saudi Arabia concludes a so-called 123 Agreement for Cooperation on Peaceful Uses of Atomic Energy with the United States.

Overall, in terms of the cost of power, new nuclear is clearly losing to wind and photovoltaics. As WNISR2020 shows, investment in new nuclear is about one tenth that in wind and photovoltaics (Figure 49). The high capital cost of nuclear power plants requires that they operate almost continually to bring down the capital charge per kilowatt-hour. They must therefore compete directly with renewables most of the time or store their output to be used during cloudy, windless periods. Storage does not relieve the competition with wind and solar, however, because, as renewables expand and storage costs come down, they too will have increasing incentives to store their excess output.

The biggest social argument for nuclear powerplants is that their carbon emissions are low. Currently, existing nuclear power plants are usefully producing a little less than one third of global low-carbon-emission electric power. Increasingly, therefore, the issue is not one of nuclear new-builds but nuclear life extension. Even there, however, nuclear is struggling. As WNISR2020 makes convincingly evident, in some major countries such as the United States, even 30-year-old plants whose capital costs have been paid off cannot compete economically with new renewable power plants, whose capital costs have been declining. The operating costs of nuclear plants are high in part because one to two hundred workers and guards are required on site per reactor at all times in case of accident or terrorist attack. Subsidies justified by their low carbon emissions have become critical to the continued operation of many U.S. nuclear power plants.

A recent event in South Korea has, however, raised concerns about sudden shutdowns in nuclear power plants as a result of the extreme weather events that are becoming more frequent as a result of climate change. On 3 September 2020, South Korea's Nuclear Safety and Security Commission announced that four reactors at Kori Nuclear Power Plant had shut down automatically early that morning because of typhoon impacts on their power transmission lines. Prior to the shutdown, the four reactors had been providing about 7 percent of the country's total power generation. Experts are concerned that, under different circumstances, the sudden shutdowns could destabilize South Korea's grid and cause large-scale blackouts.[5]

4 - Choi Ha-yan, "Cracks found in containment building of UAE nuclear power plant built by S. Korean companies", *The Hankyoreh*, 17 December 2018, see http://english.hani.co.kr/arti/english_edition/e_international/874728.html.

5 - Kim Jeong-su, "Busan's Kori Nuclear Power Plant loses power due to Typhoon Maysak", *The Hankyoreh*, 4 September 2020, see http://english.hani.co.kr/arti/english_edition/e_national/960820.html.

What about the arguments for phasing out fission faster than will happen naturally as retirements exceed new builds? From our perspective, the most important consideration is nuclear-weapon proliferation. Nuclear war remains an existential danger to civilization, comparable to the destabilizing dangers of climate change. The difference is that, while we can see climate change happening gradually, nuclear war could come upon us suddenly, by surprise, as a result of some terrible mistake, hacking or a deranged leader. The proliferation of nuclear weapons to more countries increases the probability of such events.

Historically, the nuclear energy community's early infatuation with plutonium breeder reactors facilitated nuclear weapon programs in France, India, Israel and the United Kingdom. Military dictatorships in Argentina, Brazil, South Korea and Taiwan started down the same track but were delayed by external pressure long enough for anti-nuclear-weapon democratic Governments to take over.

Thanks to the "invisible hand" of economics, the threat of nuclear proliferation and nuclear terrorism from plutonium separation have receded. The capital costs of sodium-cooled plutonium "breeder" reactors are higher than those of light water reactors (LWRs) and using plutonium as fuel in LWRs costs ten times as much as low-enriched uranium fuel. Yet breeder advocates in China, France, India, Japan and Russia still succeed in persuading their gullible Governments to keep plutonium programs alive and, in South Korea and the United States, are even promoting new programs.

The Korea Atomic Energy Research Institute (KAERI) has been campaigning for decades for South Korea's "right" to reprocess, like Japan. During the renegotiation of the U.S.-ROK Agreement on Peaceful Nuclear Cooperation, the United States managed put the issue off with a 10-year joint "feasibility study", but that study is to be completed in 2021 and KAERI is starting to press again.

KAERI's advocacy has centered on its claim that reprocessing will solve the problem of the accumulation of spent fuel in the pools of South Korea's nuclear power plants. On-site dry-cask storage has dealt with this problem at the Wolsong nuclear power plant whose heavy water reactors filled their pools years ago. Majorities in local communities and nuclear-energy opponents strongly oppose on-site dry-cask storage at other nuclear power plants, however, fearing that the power plants will become permanent storage sites for spent fuel.

Some Government officials and members of the National Assembly also argue that reprocessing could provide a latent nuclear deterrent against North Korea's nuclear threats. Those voices are much less significant in the Moon Administration than in the opposition but, in politics, nothing is permanent.

In the case of uranium enrichment, the invisible hand has been facilitating proliferation. Enrichment is required by most current-generation nuclear power plants. The advent of low-cost gas centrifuge enrichment plants made small enrichment plants affordable to Brazil, Iran, North Korea and Pakistan. All four sought those plants in order to produce highly enriched uranium for bombs. Fortunately, Brazil and Iran changed their minds, but they could change their minds again and other countries could easily go down the same track.

The only answer to the spread of national enrichment plants is to put enrichment under multinational or international control. The success of URENCO, jointly owned by Germany, the

Netherlands and the United Kingdom and owner of 30 percent of global enrichment capacity, shows that multinational enrichment is feasible. The global overcapacity of enrichment – with a resulting price for enrichment services insufficient to pay back the capital costs of new investments even in large plants – shows that there is no economic justification for new national enrichment plants. Hopefully, future issues of WNISR will include discussions of developments relating to reprocessing and enrichment.

The second argument for accelerating the phaseout of nuclear power is nuclear accidents. Unlike nuclear war, these are not civilization-destroying events but, as the Chernobyl and Fukushima accidents have shown, they have long-term consequences that are highly traumatic for society. Witnessing those ordeals was enough to convince Germany and Taiwan to accelerate the phase-outs of their nuclear power capacity and many other countries to cut back or cancel decisions to build new nuclear plants.

We congratulate the authors and editors of WNISR for their objective and in-depth coverage of a very controversial subject. We hope this effort will continue. The nuclear industry will be with us for decades to come. How it evolves will impact the future of international security as well as the future energy supply. It needs watching and we are grateful that WNISR is doing so.

KEY INSIGHTS

Nuclear Power in the Age of COVID-19

Unprecedented

COVID-19 is the first pandemic directly, significantly impacting the nuclear industry.

Large Outbreaks

Russia's Rosatom reported about 4,500 infections, France's EDF about 600 cases. In the U.S., a single reactor site undergoing refueling reported 200–300 infections, and the only nuclear construction site in the country had over 800 cases. Most operators/regulators have not released precise numbers.

Degraded Safety and Security

Many testing, maintenance and repair activities have been canceled or suspended or carried out under improper conditions with social distancing rules in place. The effects of these will only become evident in the months and years to come.

Critical Staff Issues

Particular groups of staff highly trained for a given specific facility (control-room operators, security staff) are difficult to replace. They remain at risk of infection.

Staff Shortages

EDF, for example, put two thirds of its nuclear staff on remote work. Subcontractors complained about lack of onsite oversight, leading to accidental injuries at least in one documented case.

Long Work Hours

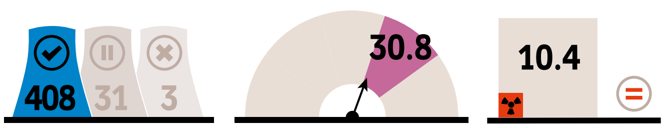
The U.S. nuclear regulator, for example, granted operators permission to impose up to 16 work hours in any 24-hour period, up to 86 work hours in any 7-day period and 12-hour shifts up to 14 consecutive days.

Onsite Inspections

by safety authorities were suspended for weeks in several countries.

Economic Crash

Nuclear utilities have been hard hit economically as operational costs went up, while bulk prices temporarily dropped and electricity consumption plunged.



World Operating Fleet at 30-Year Low

As of 1 July 2020,

31 countries operated **408 nuclear reactors**, a decline of 9 units compared to mid-2019—10 less than in 1989 and 30 fewer than the 2002 peak of 438.

In total, **31 reactors**—including 24 in Japan—are in Long-Term Outage (LTO).

3 units closed, not a single unit started up in the first half of 2020.

The total operating nuclear capacity declined by 2.2 percent from one year earlier to reach **362 GW** as of mid-2020.

The mean age of the world's nuclear fleet has increased steadily since 1984 and now stands at about 31 years with 20 percent reaching 41 years or more.

Nuclear energy's share of global gross electricity generation marked a break in its slow but steady decline from a peak of 17.5 percent in 1996, with a 0.2 percentage-point increase over the 10.15 percent in 2018 to **10.35 percent** in 2019.

Russia Drives Global Constructions

Six reactors started up in 2019, three in Russia, two in China, one in South Korea, yet seven less than scheduled at the beginning of the year. Five units were closed.

Russia is involved in 15 of the 52 construction projects in 8 of the 17 countries building.

China Short-Term Driver, Long-Term Enigma

In 2019, nuclear power generation in the world increased by **3.7 percent** of which half due to a 19 percent increase in China.

Three units were closed, not a single unit started up in the first half of 2020, including in China.

After declining for 5 years, the number of units under construction increased by 6 to 52 as of mid-2020 (incl. 15 in China) but remains well below the 69 units at the end of 2013.

In 2019, construction began on 6 reactors (incl. 4 in China), and on one in the first half of 2020 (in Turkey).

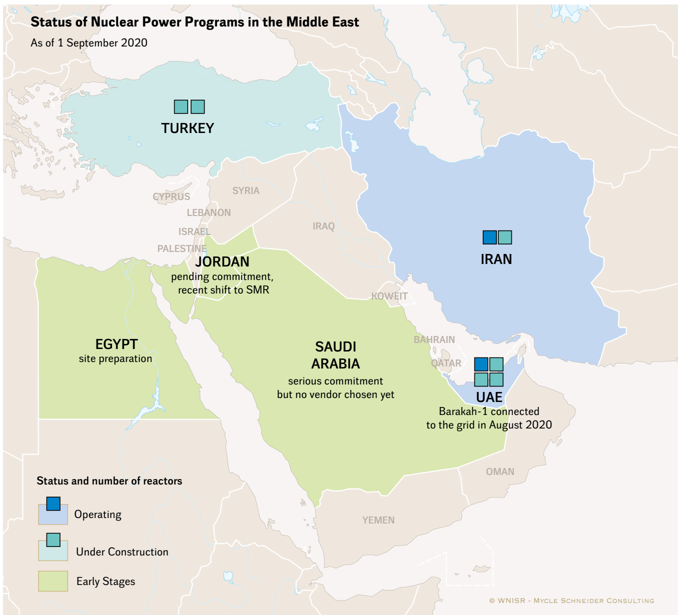
China will miss its Five-Year-Plan 2020 nuclear targets of 58 GW installed and 30 GW under construction.

China still leads renewable energy investments with US$83 billion.

Global Construction Delays Worsen

At least **33** of the 52 units under construction are behind schedule; 12 have reported *increased* delays and 4 have had documented delays for the first time over the past year.

In **8 cases** (15 percent), first construction starts date back 10 years or more, including two units that had construction starts 35 years ago and one unit that goes back 44 years.



Middle East Focus

Six countries with nuclear power interests: **Iran, UAE, Turkey, Egypt, Saudi Arabia and Jordan** (by order of program advancement). Natural gas dominates power generation.

One operating reactor (in Iran) generating less than 2 percent of electricity in the country. In addition, Barakah-1 (UAE) started up in August 2020, first reactor in the Arab world.

Six units are under construction, in UAE (3), in Turkey (2) and Iran (1).

Five are behind schedule and one just started. At the most, one other construction start could happen over the year in the region (in Egypt).

Comparisons between nuclear and solar options show a large and widening gap. For example, a contract for 1.2 GW of solar power at US$24.2/MWh, signed in 2017 and connected to the grid in 2019, is **5–8 times cheaper** than the international cost estimate for nuclear of US$118–192/MWh.

Renewables Continue to Thrive

A new record **184 GW** (+20 GW) of non-hydro renewables were added to the world's power grids in 2019. Wind added 59.2 GW and solar-photovoltaics (PV) 98 GW. These numbers compare to a net 2.4 GW increase for nuclear power.

Total investment in new-renewable electricity exceeded **US$300 billion**, ten times the reported global investment decisions for nuclear power.

Over the past decade, levelized cost estimates for utility-scale solar dropped by 89 percent, wind by 70 percent, while nuclear increased by 26 percent.

EXECUTIVE SUMMARY AND CONCLUSIONS

The World Nuclear Industry Status Report 2020 (*WNISR2020*) provides a comprehensive overview of nuclear power plant data, including information on age, operation, production, and construction of reactors. A new focus chapter in this year's report is Nuclear Power in the Age of COVID-19 that assesses the safety and security implications of operating nuclear facilities in a pandemic and provides a country-by-country overview of available information on staff infections, impacts and measures. Another special focus is the chapter on Nuclear Power in the Middle East that analyses the significance of the first operating nuclear power plant in the Arab world and the status of nuclear programs in five other countries in the region.

The WNISR assesses the status of new-build programs in the 31 nuclear countries (as of mid-2020) as well as in potential newcomer countries. WNISR2020 includes sections on seven Focus Countries representing about two-thirds of the global fleet. The Fukushima Status Report looks at onsite and offsite impacts of the catastrophe that began in 2011. 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 offers comparative data on investment, capacity, and generation from nuclear, wind and solar energy around the world. Finally, Annex 1 presents overviews of nuclear power in the countries not covered in the Focus Countries sections.

REACTOR STARTUPS & CLOSURES

Startups. At the beginning of 2019, 13 reactors were scheduled for startup during the year; only six made it, three in Russia, two in China and one in South Korea. No new reactor started up worldwide in the first half of 2020, including in China.[6]

Closures. Five units were closed in 2019, of which two in the U.S., and one each in Germany, Sweden and Switzerland. Eight additional reactors were officially closed in Japan (5), Russia (1), South Korea (1) and Taiwan (1); most of these had not generated power in years.[7] In the first half of 2020, three additional units were closed, two in France and one in the U.S.

OPERATION & CONSTRUCTION DATA[8]

Reactor Operation and Production. As of 1 July 2020, 31 countries operating 408 nuclear reactors—excluding Long-Term Outages (LTOs)—a decline of nine units compared to

6 - One unit was connected to the grid in China in August 2020, after more than a year without startups. One has to go back to the immediate aftermath of the Fukushima disaster in 2011 to find a period exceeding one year without a single startup in China. Barakah-1 in the United Arab Emirates was also started up in August 2020.

7 - 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.

8 - See Focus Countries and Annex 1 for a country-by-country overview of reactors in operation and under construction as well as the nuclear share in electricity generation.

WNISR2019[9]—10 less than in 1989 and 30 fewer than the 2002 peak of 438. Of the 28 reactors in LTO as of mid-2019, one was restarted, and one was closed; with five units entering the LTO category, there is, as of mid-2020, a total of 31 units in LTO as of mid-2020,[10] all considered operating by the International Atomic Energy Agency (IAEA). These include 24 reactors in Japan (no change), three in the U.K., two in South Korea, and one each in China and India.

The total operating capacity declined by 2.1 percent from one year earlier to reach 362 GW as of mid-2020.[11]

Annual nuclear electricity generation reached 2,657 net terawatt-hours (TWh or billion kilowatt-hours) in 2019, a 3.7 percent increase over the previous year—half of which is due to China's nuclear output increasing by over 19 percent—and only 3 TWh below the historic peak in 2006.

The "big five" nuclear generating countries—by rank, the United States, France, China, Russia and South Korea—again generated 70 percent of all nuclear electricity in the world in 2019. Two countries, the U.S. and France, accounted for 45 percent of 2019 global nuclear production, that is 2 percentage points lower than in the previous year, as France's output shrank by 3.5 percent.

Share in Electricity/Energy Mix. Nuclear energy's share of global commercial gross electricity generation has marked a break in its slow but steady decline from a peak of 17.5 percent in 1996, with a small 0.2 percentage-point increase over the 10.15 percent in 2018 to 10.35 percent in 2019.

Nuclear power's share of global commercial primary energy consumption has remained stable since 2014 at around 4.3 percent.

Reactor Age. In the absence of major new-build programs apart from China, the average age of the world operating nuclear reactor fleet continues to rise, and by mid-2020 reached 30.7 years. The mean age of the world's fleet has been increasing since 1984, when it stagnated.

A total of 270 reactors, two-thirds of the world's operating fleet, have operated for 31 or more years, including 81 (20 percent of the total) that have operated for 41 years or more.

Lifetime Projections. If all currently operating reactors remained on the grid until the end of their licensed lifetime, including many that already hold authorized lifetime extensions (PLEX Projection), and all units under construction scheduled to have started up, an additional 135 reactors or 105 GW (compared to the end-of-2019 status) would have to be started up or restarted prior to the end of 2030 in order to maintain the status quo. This would mean, in the *coming* decade, the need to more than double the annual building rate the *past* decade from 5.8 to 13.7. Construction starts are on a declining trend. The required number of new units might be even higher because many reactors are being shut down long before their licenses are terminated; the mean age at closure of the 17 units taken off the grids between 2015 and 2019 was 42.4 years.

9 - Unless otherwise noted, all figures indicated reflect the situation as of 1 July 2020. One unit was connected to the grid in the United Arab Emirates in August 2020 making it the 32nd country to operate nuclear power plants, and one in China.

10 - +2 startups +1 restart –5 new LTOs –7 closures = -9 net

11 - All figures are given for nominal net electricity generating capacity. GW stands for gigawatt or thousand megawatts.

Construction. Seventeen countries are currently building nuclear power plants, one more than in mid-2019, as Iran restarted construction of Bushehr-2 site, originally launched in 1976. As of 1 July 2020, 52 reactors were under construction—six more than WNISR reported for mid-2019 but 17 fewer than in 2013—of which 15 in China with 14 GW of capacity, less than half of the 5-Year target of 30 GW under construction by the end of 2020.

Total capacity under construction in the world increased by 8.9 GW to 53.5 GW. The current average time since work started at the 52 units under construction is 7.3 years, on the rise for the past two years from an average of 6.2 years as of mid-2017. Many units are still years away from completion.

- *All* reactors under construction in at least 10 of the 17 countries have experienced mostly year-long delays. At least 33 (64 percent) of all building projects are delayed.
- Of the 33 reactors clearly documented as behind schedule, at least 12 have reported *increased* delays and four have reported *new* delays over the past year.
- Thirteen reactors were scheduled for startup during 2019, but only six made it.
- Construction start of two projects dates back 35 years, Mochovce-3 and -4 in Slovakia, and their startup has been further delayed, currently to 2020–2021. Bushehr-2 originally started construction in 1976, that is 44 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2024.
- Five reactors have been listed as "under construction" for a decade or more: the Prototype Fast Breeder Reactor (PFBR) in India, Olkiluoto-3 (OL3) in Finland, Shimane-3 in Japan, the Flamanville-3 (FL3) in France, and Leningrad 2-2 in Russia. The Finnish project has been further delayed this year, grid connections of the French and Indian units are likely to be postponed again, and the Japanese reactor does not even have a provisional startup date.
- Nine countries completed 63 reactors—with 37 in China— over the past decade, with an average construction time (start to grid connection) of 10 years.

CONSTRUCTION STARTS & NEW-BUILD ISSUES

Construction Starts. In 2019, construction began on six reactors—four in China and one each in Russia and the U.K.—and in the first half of 2020 on one (in Turkey). These were the first construction starts of commercial reactors in China since December 2016. This compares to 15 construction starts in 2010 and 10 in 2013. Construction starts peaked in 1976 at 44.

Over the decade 2010–2019, construction began on 67 reactors in the world. As of mid-2020, only 18 have started up, while 44 remain under construction (5 cancelled).

Construction Cancellations. Between 1970 and mid-2020, a total of 93— one less than in WNISR2019 as Bushehr-2 restarted construction in 2019—that is one in eight of a total of 773 constructions were abandoned or suspended in 19 countries at various stages of advancement.

NUCLEAR POWER IN THE AGE OF COVID-19

COVID-19 is the first pandemic of this scale in the history of nuclear power. Nuclear utilities have been fast to point to the "crucial" role nuclear power played during the pandemic as a source of electricity. But the picture is more complex, with various safety and security routines becoming more difficult or impossible during a pandemic:

- **Periodic and frequent testing** is usually done at systems to provide assurance that vitally important functions like the emergency control room operations, emergency electricity supply or emergency core cooling are in good working order.
- Normally periodic testing and inspections are performed under **the four-eyes principle** (**at least two people have to be always present**), which becomes challenging if social distancing is followed.
- Particular staff groups, like control-room personnel, with specific knowledge and qualification for specific facilities cannot easily be replaced.
- Emergency situations like a fire or toxic gas buildup in the control-room could easily be exacerbated by the need of social distancing; the challenge is even greater in the emergency control-room.
- Infections amongst **security staff**, a limited number of highly trained forces for specific facilities, could rapidly lower the protection level.

Infections, and Operator Response Strategies. Systematic national reporting on infections amongst nuclear staff did not happen anywhere, with the remarkable exception of Russia's Rosatom, whose Director General made weekly video presentations on the evolution of active cases and recovered persons.

- **Russian Rosatom** graphic illustrations indicate a total of about **4,500** infections in the group, with 1,200 still recovering as of the end of July 2020.
- Only a handful of infections have been reported from nuclear facilities in **Japan** and **South Korea**.
- **French utility EDF** in mid-June 2020 indicated around **600 cases** amongst the nuclear staff over a 12-week period, reaching around 2 percent at the peak of the pandemic.
- The **Swedish** regulator reported "few cases" but did not give numbers.
- At the **U.K.** Sellafield site about **1,000 employees** self-isolated and the reprocessing plant was shut down. At least one EDF Energy employee died of COVID-19 at the Hinkley Point C construction site but no numbers have been published about tested/infected staff.
- In the **U.S.**, several nuclear power plant sites have reported up to dozens of infected staff (e.g. Limerick, Waterford). At the Millstone reactor, three operators were amongst those that tested positive. An outage at Fermi-2 may have led to **200-300 infections**. Operator DTE Energy refused to disclose exact numbers.

While numerous fuel-chain and research facilities were shut down, no country reported an enforced shutdown of a nuclear power plant. Various measures were taken, including:

- Operators dramatically **reduced staff levels** in nuclear plants, e.g. in France, 15,000 employees (two thirds) of EDF's Nuclear Generation Division were put on telework. Reduced staff levels led to a **lack of oversight** of subcontractors.[12]
- Regulators granted operators permission to impose **strikingly long work hours**. For example, in the U.S., workers could work for up to 16 work hours in any 24-hour period and up to 86 work hours in any 7-day period or 12-hour shifts for up to 14 consecutive days.
- In some cases, e.g. in Russia and Sweden, control-room staff and essential personnel were **isolated**, and/or onsite housing was provided for workers during outages (also in the U.S.).
- S**ocial distancing** and **remote working** practices have been employed widely, but implementation seems to have varied in degrees of speed and rigor. In some cases, trade unions have reported practices very different from operator declarations, complaining about lack of masks and insufficient social distancing. In France, workers walked off at least three reactor sites considering their health and safety were not appropriately protected.
- Force-on-force **exercises** in the U.S. as well as many other security and safety training-sessions in several countries have been **suspended** during the pandemic, leading to a degraded readiness level.
- In many cases, **refueling and maintenance outages** have been altered to eliminate "non-critical work" or were **deferred entirely** to the end of the year or even into 2021. In some cases, like at Germany's Grohnde and Spain's Trillo-1, outages have been **stretched out** to allow for a lower density of workers.
- In some cases, e.g. at Canada's Darlington-3 or Romania's Cernavoda-1, planned **major overhaul** has been **rescheduled**. In France, the installation of emergency diesel generators at five reactors was delayed for a second time, to February 2021, two years after the first delay was granted.
- The pace of **construction** in at least 12 of the current 17 countries building nuclear reactors has been **impacted**, but apparently only in Argentina construction activities were entirely halted (on CAREM-25). A large outbreak took place at the Vogtle plant in Georgia, the only nuclear construction site in the U.S., where **over 800 staff** tested positive, with over 100 still affected as of late August 2020. As of late May 2020, about 100 cases were reported at the Belarus Ostrovets site.

Infections, and Regulator Response Strategies. Very little information has been made public about infections at national safety authorities and their Technical Support Organizations (TSOs). Some examples of infection levels and measures include:

- French regulator **ASN** claims that as of early August 2020 not a single staff person had tested positive. In late April 2020, the French TSO **IRSN** said **59** were "contaminated or likely to be", all of whom recovered, but strangely another IRSN spokesperson said in early September 2020 that only nine people were actually tested positive and only 13 total of 1,800 staff were tested at all.[13] Apparently, neither ASN nor IRSN have systematic testing programs in place.
- Safety authorities and their TSOs in several countries (e.g. Canada, Finland, France, U.S.) decided to **halt site visits** (**except in cases of emergency**). ASN carried out about 6 percent

12 - E.g. lack of oversight led to two workers being injured during a hydrogen explosion and ensuing fire at the Belleville station in April 2020.

13 - Audrey Lebeau-Livé, personal communication, IRSN, Email to Mycle Schneider, 1 September 2020.

of the number of inspections it carries out on average under normal circumstances. IRSN also entirely suspended environmental sampling.

- Regulators generally have been very **"pragmatic"** and **"flexible"** in their decision-making and approved most operator requests for exemptions, exceptions and deferrals.

Degradation of Safety and Security. Nuclear officials in international organizations, industry groups, utilities and regulatory authorities have claimed in one way or another that all these measures were taken "while maintaining the required level of safety", as ASN put it. The U.K. Office for Nuclear Regulation (ONR) found "no significant change to dutyholders' safety and security resilience".

This confidence is difficult to comprehend because working conditions have clearly deteriorated in many nuclear facilities, because scheduled repair and upgrading work was often not carried out or delayed for many months, and operators of many nuclear power plants in the world were left without any physical regulatory oversight as inspectors stayed home. So not only valves, joints, pipes and weldings were not checked by the operators as planned, but no physical inspection actually made sure that operators were doing what they said they were doing. Considering the long list of fraud cases in the industry (for a selection see Introduction to Nuclear Power in the Age of COVID-19), fully operational independent regulators and their TSOs remain a crucial ingredient to nuclear safety and security.

Even if the pandemic were to slow down—there is of course no guarantee that no second wave hits nuclear countries—the situation will take time to significantly improve. Operators and regulators will be struggling to get back to operational modes that are closer to normality, leave alone catching up on all of the delayed activities, which will likely take several years.

In addition, bulk prices plunged as operational costs went up, bulk prices dropped and electricity consumption plunged. The financial viability of some of these utilities may be at stake. Indispensable cost cutting exercises will further exacerbate the pressure.

This is far from over.

MIDDLE EAST FOCUS

On the occasion of the first nuclear power plant entering the operational phase in an Arab country, i.e. Barakah in the United Arab Emirates (UAE), WNISR provides an overview of the nuclear energy ambitions of six countries in the Middle East: Iran, UAE, Turkey, Egypt, Saudi Arabia and Jordan (ordered by level of program advancement).

The region mainly depends on natural gas for electricity generation with five of the six assessed countries generating more than half of their power from gas; of these, three countries (Egypt, Jordan, UAE) rely on gas for more than 75 percent of the electricity.

Iran has one reactor in operation and another one under construction as well as various activities along the nuclear fuel chain. UAE has started up one unit in early August 2020, while three more reactors remain under construction. Turkey has two units under construction. As for Egypt, Saudi Arabia and Jordan, nuclear plans are more or less advanced, but no construction has yet begun. Egypt, Jordan and Turkey are struggling with high debt loads and unfavorable credit-ratings (highly speculative or "junk"). This makes capital-intensive investments like nuclear power particularly challenging, unless financing assistance from vendor countries is provided. While Egypt and Turkey have benefited from Russian financial assistance, Jordan is yet to obtain any financial aid.

Iran

- **Construction** had been disturbed by decades-long suspensions. Even after construction of Bushehr-1 had restarted in 1996, the project was plagued by delays and connected to the grid only in 2011, 35 years after construction first started, 15 years after construction restart.
- **Production** remains modest and in 2019, Bushehr-1 represented less than 2 percent of electricity generation in the country.
- According to official estimates, Iran's **solar capacity** potential is a stunning 40 TW (40,000 GW).

United Arab Emirates

- **Construction** of the Barakah plant by the Korean Electric Power Corp. (KEPCO) is about three years behind schedule. Barakah-1 was planned to start up in 2017[14], with Units 2, 3 and 4 following each other with one-year distance. Amongst the reasons for delays were construction problems (cracks/voids in the containment) and difficulties in establishing a local, trained operator workforce.
- **Cost comparisons** between the nuclear and solar options show:
  - The official cost estimate of Barakah power of US$72/MWh in 2012 was below the lowest level of *Lazard's* international cost range for the year of US$78–114;
  - A Power Purchasing Agreement (PPA) for a 1.2 GW solar photovoltaic capacity signed in 2017 at US$24.2/MWh; the plant was connected to the grid in 2019.
  - Earlier in 2020, a solar power bid was made by EDF/Jinko for 1.5 GW at US$13.5/MWh, five times lower than the no doubt underestimated original cost of Barakah power and 9–14 times below *Lazard's* nuclear cost estimate for 2019 of US$118–192/MWh.

Turkey

- **Construction** at Akkuyu-1 was launched by Russian builder Rosatom in April 2018 followed by Akkuyu-2 in April 2020. Startup for the first unit was planned for 2023, which is unlikely to happen. The Akkuyu project has been in the planning since the 1970s and was delayed countless times. The construction itself was hampered with technical problems including cracks identified in the basemat that had to be repaired. Nuclear power has met with fierce opposition, nationally and locally, concerned about nuclear safety, earthquake risks and negative social impacts. Two thirds of Turkish people polled opposed nuclear power in a 2018 survey.
- Cost comparisons between the nuclear and solar options show that in 2018 solar PPAs came in at US$65/MWh, almost half the cost for nuclear electricity estimated in 2012.

14 - It was finally connected to the grid on 19 August 2020.

Jordan

- Project Planning. Eleven years after the first feasibility study for nuclear energy, in 2018, Jordan pulled the plug on any project for large nuclear power plants and focused planning on Small Modular Reactors (SMRs). After signing cooperation agreements with potential vendors from China, Russia, U.K. and the U.S. no further progress has been made.
- **Cost comparisons** between the nuclear and solar options show a 2012-nuclear-cost estimate at around US$100, compared to a 2017-PPA for 50 MW solar at US$59/MWh connected to the grid in late 2019, and a bid at US$25/MWh in 2018. The country set a 20-percent target from renewable sources in the power mix for 2025.

Egypt

- **Project Planning.** The Egyptian Atomic Energy Commission was established in the mid-1950s and the idea of building nuclear power plants was explored as early as the mid-1970s. But it took until 2016 to sign a loan agreement with Russia for the construction of four Rosatom reactors. In March 2019, a site permit was issued for Dabaa on the Mediterranean cost. Construction is planned to begin in 2020.
- **Cost comparisons** show a 2015-estimate for nuclear power at US$110/MWh vs. a 2019-PPA for solar power at US$24.8/MWh, four times cheaper. In 2016, the Government set a 37-percent-share target for renewables in the electricity mix by 2035 vs. 3 percent for nuclear energy.

Saudi Arabia

- **Project Planning.** In 2018, the Government approved a nuclear program of two reactors to be built in the 2020s, and possibly more later. However, no vendor has been chosen and no site selected. The Government has also been interested in the development of domestic uranium mining and enrichment for fuel. The country has also shown interest in the development of SMR technology, without much tangible progress so far.
- **Cost comparisons** between the nuclear and renewable energy options are not possible because there are no cost estimates for nuclear power. However, a PPA for solar power at US$16/MWh, signed in 2016, underlines the competitiveness of photovoltaic electricity in the region.

FOCUS COUNTRIES

The following seven Focus Countries covered in depth in this report represent almost one fourth of the nuclear countries hosting about two-thirds of the global reactor fleet. Key facts for year 2019:

China. Nuclear power generation grew by 19.2 percent in 2019 and contributed 4.9 percent of all electricity generated in China, up from 4.2 percent in 2018. Plans for future expansion remain uncertain.

Finland. Nuclear generation reached a new record in 2019. The Olkiluoto-3 EPR project was delayed yet again, and, according to an announcement from April 2020, "regular production of electricity" will not happen before February 2022; that constitutes nearly two years of additional delay since the previous announcement only one year earlier, and 13 years after the original planned startup date.[15]

France. Nuclear plants generated 3.5 percent less power than in 2018, representing 70.6 percent of the country's electricity, the lowest share in 30 years. Outages at *zero capacity* cumulated 5,580 reactor-days or more than three months per reactor on average. All outages at 54 of the 58 units were extended beyond the planned duration, leading to an average 44-percent increase of the outage time. A damning report by the Court of Accounts slams the lack of government oversight of the Flamanville-3 EPR construction project that is at least 10 years behind schedule and recalculated the cost at over €$_{2015}$19 billion (US\$$_{2020}$20 billion) including financing.

Japan. Nuclear plants generated more power than in any year since Fukushima disaster began in 2011 and provided 7.5 percent of the electricity in 2019. As of mid-2020, nine reactors had restarted but that number has not increased since mid-2018. Four units were taken off the grid again in mid-2020 for various reasons, and power output is expected to drop by up to half in 2020. A large bribery scandal involving KEPCO management including the president rattled the industry.

South Korea. Nuclear power output recovered by 9 percent after a decline of 19 percent since 2015 and supplied 26.2 percent of the country's electricity. If adopted, a draft energy bill under review would further reduce nuclear's role to providing just 10 percent of power by 2034.

United Kingdom. Nuclear generation decreased again and provided only 14 percent of the power in the country, down from 17.7 percent in 2018. The fleet's aging units, over 36 years on average, are struggling with many technical issues, in particular irreparable damage to moderator graphite bricks leading to lengthy outages of the Advanced Gas-cooled Reactors (AGRs). Three units newly qualified for the LTO category. While construction officially started at Hinkley Point C-2, prospects for other new-build projects remain uncertain.

United States. Nuclear power plants generated a new historic maximum of 809 TWh (+1.4 TWh), while their share in the electricity mix remained below 20 percent (19.7 percent). The continuous excellent productivity of the ageing U.S. fleet, average age 40 years, is intriguing and contrary to the performance of other early programs. The NRC issued its first license extension to 80 years. But nuclear units have increasing difficulties to economically compete in the market. State subsidies have been granted to four uneconomic nuclear plants to avoid their "early closure". Following the revelation of an unprecedented corruption scheme in Ohio, involving the State's Speaker of the House, two of these "bailouts" might be reversed. Many other units remain threatened with early closure for economic reasons. A series of other criminal affairs involving the nuclear industry were revealed over the past two months.[16]

15 - TVO, "OL3 EPR regular production of electricity starts in February 2022", Press Release, 28 August 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprregularproductionofelectricitystartsinfebruary2022.html, accessed 4 September 2020. This latest announcement happened after the editorial deadline for the main body of this report.

16 - These developments happened after the editorial deadline for the main body of this report. See Introduction for the gist of the cases.

SMALL MODULAR REACTORS (SMRs)

Following assessments of the development status and prospects of Small Modular Reactors (SMRs) in WNISR2015 and WNISR2017, this year's update does not reveal great changes.

Argentina. The CAREM-25 project under construction since 2014 is reportedly 55 percent complete. A significant construction interrupted work in November 2019 complaining about late payments and design changes. COVID-19 led to a complete construction stop.

Canada. Three provincial Governments have embraced the idea to promote SMRs for remote communities and mining operations. Various models are being investigated. The environmental impact assessment process for the proposed first demonstration high temperature reactor is underway.

China. A high-temperature reactor under development since the 1970s has been under construction since 2012. Startup has been delayed several times and is now planned for 2021, four years later than scheduled.

India. An Advanced Heavy Water Reactor (AHWR) design has been under development since the 1990s, and its construction start is getting continuously delayed. No major news since WNISR2019.

Russia. Two "floating reactors" were finally connected to the grid in December 2019. As construction started in 2007, it took about four times as long as planned. The costs were estimated at US$740 million in 2015 (likely underestimated) or US$11,600 per installed kilowatt, significantly more expensive than the most expensive Generation III reactors.

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 nobody wants to build it in the country, because it is not cost-competitive.

United Kingdom. Rolls-Royce is the only company interested in participating in the Government's SMR competition but has requested significant subsidies, including for investing in a factory. The Rolls-Royce pre-design is at a very early stage but, at 440 MW, it is not really small. As of 1 September 2020, the design was not even under examination by the regulator.

United States. The Department of Energy (DOE) has generously funded companies promoting SMR development. A single design by NuScale is in the final stage of the design certification process.[17] However, the Nuclear Regulatory Commission and the Advisory Committee on Reactor Safeguards identified some significant safety problems that will have to be resolved in the future.

Overall, there are few signs that would hint at a major breakthrough for SMRs, either with regard to the technology or with regard to the commercial side.

17 - U.S.NRC, "NRC Issues Final Safety Evaluation Report for NuScale Small Modular Reactor", Nuclear Regulatory Commission, 28 August 2020, see www.nrc.gov/reading-rm/doc-collections/news/2020/20-043.pdf, accessed 4 September 2020.

FUKUSHIMA STATUS REPORT

Over nine years have passed since the Fukushima Daiichi nuclear power plant accident (Fukushima accident) began, triggered by the East Japan Great Earthquake on 11 March 2011 (referred to as 3/11 throughout the report) and subsequent events. The onsite situation is still not stabilized and numerous offsite challenges remain.

Onsite Challenges

Spent Fuel Removal from the pool of Unit 3 started in April 2019. Only about one fifth had been removed one year on. Units 1 and 2 have not gotten beyond the preparatory stage.

Fuel Debris Removal is now planned to start with Unit 2 by 2021. Further delays are likely.

Contaminated Water Management. Water injection continues to cool the fuel debris of Units 1–3. 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. The commissioning of a dedicated bypass system and the pumping of groundwater has reduced the influx of water from around 400 m3/day to about 170 m3/day. However, in FY2019, pumped contaminated water increased again to 180 m3/day. An equivalent amount of water is partially decontaminated and stored in 1,000-m3 tanks. Thus, a new tank is needed every 5.5 days. The storage capacity onsite of 1.4 million m3 is expected to be saturated by the end of 2022. Plans to release the contaminated water into the ocean are widely contested, including overseas.

Worker Health. As of March 2020, there were 7,000 workers involved in decommissioning work on-site, 87 percent of whom were subcontractors; only the remaining 13 percent worked for Tokyo Electric Power Company (TEPCO). Maximum effective dose levels accepted for subcontractors turned out eight times higher than for TEPCO employees.

Offsite Challenges

Amongst the main offsite issues are the future of tens of thousands of evacuees, the assessment of health consequences of the disaster, the management of decontamination wastes and the costs involved.

Legal Issues. In September 2019, the Tokyo District Court acquitted three former TEPCO top managers accused of professional negligence resulting in injury or death. The ruling was widely condemned as flawed, and the lawyers for the plaintiffs have filed an appeal to the Tokyo High Court.

Evacuees. As of April 2020, almost 39,000 Fukushima Prefecture residents—not including "self-evacuees"—were still officially designated evacuees. According to the Prefecture, the number peaked just under 165,000 in May 2012. The Government intends to continue the lifting of restriction orders for affected municipalities. However, according to a recent survey, only 1.8 percent of the people returned to Okuma Town and 7.5 percent to Tomioka Town.

Health Issues. Officially, as of February 2020, a total of 237 people had been diagnosed with a malignant tumor or suspected of having a malignant thyroid tumor and 187 people underwent surgery. While the cause-effect relationship between Fukushima-related radiation exposure and illnesses has not been officially established, questions have been raised about the examination procedure itself and the processing of information. However, a 2019-study concludes that "the average radiation dose-rates in the 59 municipalities of the Fukushima prefecture in June 2011 and the corresponding thyroid cancer detection rates in the period October 2011 to March 2016 show statistically significant relationships".

Food Contamination. According to official statistics, among over 266,000 samples taken in FY 2020, a total of only 157 food items were identified as being contaminated beyond legal limits. As of March 2020, post-3/11 import restrictions remain in place in 20 countries (three less than a year earlier).

Decontamination. The contaminated soil in the temporary storage area in Fukushima Prefecture is currently being transferred to intermediate storage facilities in eight areas. As of June 2020, around 56 percent of the total amount of 14 million m3 had been shipped. The soil is to be processed through various stages of volume reduction before being shipped to a final repository.

DECOMMISSIONING STATUS REPORT – SOARING COSTS

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.

- As of mid-2020, 189 reactors were closed, eight more than a year earlier, of which 169 are awaiting or are in various stages of decommissioning.
- Only 20 units have been technically fully decommissioned, one more than a year earlier: 14 in the U.S., five in Germany, and one in Japan. Of these, only 10 have been returned to greenfield sites.
- The average duration of the decommissioning process is about 20 years, with a large range from 6–42 years.
- Progress in decommissioning projects around the world remains slow. In **France**, the two Fessenheim reactors entered the warm-up stage and Superphénix entered the hot-zone stage. In **Germany** four reactors advanced to the hot-zone stage, while one additional reactor entered the warm-up-stage. In the **U.S.**, two more reactors entered the warm-up stage, while one plant finished the technical decommissioning process.
- Although they were early to start nuclear power programs, Canada, France, Russia and U.K. have not fully decommissioned even one reactor so far.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

Renewable energy deployment and generation has better resisted the impacts of the COVID-19 pandemic than the nuclear power sector. In the first quarter of 2020, renewables increased output by an estimated 3 percent and its relative share in global generation rose by 1.5 percentage points, while nuclear output fell by about 3 percent.

Costs. Levelized Cost of Energy (LCOE) analysis shows that between 2009 and 2019, utility-scale solar costs came down 89 percent and wind 70 percent, while new nuclear costs increased by 26 percent. The gap has continued to widen between 2018 and 2019.

Investment. In 2019, for the third time after 2015 and 2017, the total investment in renewable electricity exceeded US$300 billion, almost ten times the reported global investment decisions for the construction of nuclear power of around US$31 billion for 5.8 GW. Investment in nuclear power is less than a quarter of the investment in wind (US$138 billion) and solar (US$131 billion) individually. China remains the top investor in renewables, spending US$83 billion in 2019, down 9 percent compared to 2018.

Installed Capacity. In 2019, a new record 184 GW (+20 GW) of non-hydro renewables were added to the world's power grids. Wind added 59.2 GW and solar-photovoltaics (PV) 98 GW, both slightly below the 2017-levels. These numbers compare to a net 2.4 GW increase for nuclear power.

Electricity Generation. In 2019, annual growth for global electricity generation from solar was 24 percent, for wind power about 13 percent and 3.7 percent for nuclear power, half of which is due to China.

Low-Carbon Power. Compared to 1997, when the Kyoto Protocol on climate change was signed, in 2019 an additional 1,418 TWh of wind power was produced globally and 723 TWh of solar PV electricity, compared to nuclear's additional 394 TWh. Over the past decade, non-hydro renewables have added more kilowatt-hours than coal or gas, twice as many as hydropower, and 22 times as many as nuclear plants.

Share in Power Mix. After experiencing the strongest annual growth on record, the share in power generation from new renewables (excluding hydro) reached 10.39 percent, surpassing nuclear energy's share (10.35 percent) for the first time.

In **China**, electricity production of 406 TWh from wind alone again by far exceeded the 330 TWh from nuclear, while solar power is already at 224 TWh.

In **India**, generation from wind power (63 TWh) outpaced nuclear again, but for the first time, generation from solar energy (46 TWh) exceeded the nuclear output of 41 TWh.

In the **European Union**, solar installed capacity for the first time exceeded the nuclear one in the EU28 with 130 GW vs. 116 GW. Wind had outpaced nuclear already in 2014 and has since enlarged the gap. Renewables (incl. hydro) generated a record 35 percent of electricity, while nuclear provided 25.5 percent. Hard coal generated electricity declined by an unprecedented 32 percent and lignite power by 16 percent, while natural gas increased by 12 percent. Wind power output grew by 14 percent and solar by 7 percent, while nuclear declined by 1 percent.

In the **United States**, electricity generation from coal plunged to a 42-year low, and in April 2019, for the first time since 1885, the renewable energy sector (hydro, biomass, wind, solar and geothermal) generated more electricity than coal-fired plants. While nuclear energy's share stayed stable, it is set to decline. With three reactors closed in 2019 and the first half of 2020, and more closures expected, the nuclear capacity is shrinking. In 2019, for the first time, installed wind power exceeded installed nuclear capacity with 104 GW vs. 98 GW. Over the past decade, wind + solar have quadrupled combined electricity generation while nuclear production has not moved.

INTRODUCTION

Since the release of the previous edition of the *World Nuclear Industry Status Report* (*WNISR*) in September 2019, the world has changed dramatically and is undergoing the worst global pandemic and the most devastating global economic crisis in a century. This is in addition to the increasingly acute climate change emergency. And much has been said about the systemic interdependencies between these crises, which is not the subject of this report.

It was an obvious choice for the WNISR-Team to elaborate a focus chapter providing a preliminary international assessment on the impact of the COVID-19 pandemic on the nuclear sector and the reactions of operators and regulators (see Nuclear Power in the Age of COVID-19). The most striking outcome of the analysis is the display of confidence by the main stakeholders that "everything is fine". While most outages for maintenance and repairs were delayed, many nuclear facilities operated with a fraction of normal staffing levels, and virtually all physical inspections by safety authorities were cancelled for at least two months. Some of the large nuclear operators like the French EDF or the Russian Rosatom were hit with hundreds of COVID-19 cases. No information is publicly available about the impact on specific areas of work. How can regulators assure parliamentarians, citizens and Governments that the operators were "maintaining the required level of safety", as the French chief regulator put it[18] if they have not been on the sites for weeks?

The in-depth assessment of the safety and security implications of the COVID-19 crisis—not only in the past months, but also in the coming years, as outage schedules will be impacted over the coming at least two years—would go far beyond the scope of this report. But there is a major public interest in getting this analysis done, soon.

The second focus chapter of WNISR2020 is devoted to Nuclear Power in the Middle East. With the first nuclear power reactor starting up in the Arab world, at the Barakah site in the United Arab Emirates (UAE), it was an appropriate time to analyze the energy policies in the region and the role of nuclear power. The deployment of nuclear energy projects in a region that has a high security volatility raises additional questions such as the comparative vulnerability of energy infrastructure that are outside the scope of this report. The recent threat by the Azerbaijani Government to bomb the Armenian nuclear plant was a reminder of the security implications of an existing nuclear facility in cases of international conflict or terrorism. "The Armenian side mustn't forget", Azerbaijani Defense Ministry spokesman Vagif Dargyakhly said in a 16 July 2020 statement, "that the most advanced missile systems our army has are capable of launching a precision strike on the Metsamor nuclear power plant, and that would be a huge tragedy for Armenia".[19] Only two days earlier, *Al Jazeera* posted a video on twitter[20] that raised the possibility of attacks on the Barakah nuclear plant. Three weeks later, the first reactor of the four-unit Barakah complex was connected to the grid.

18 - ASN, "ASN makes an assessment of its oversight since the beginning of lockdown", 25 May 2020, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-makes-an-assessment-of-its-oversight-since-the-beginning-of-lockdown, accessed 28 July 2020.

19 - *NIW*, "Baku Threatens Armenia's Metsamor Nuclear Plant", 17 July 2020.

20 - *Al Jazeera*, "When nuclear risks become nuclear reality, the consequences could be devastating", Tweet posted 14 July 2020, see https://twitter.com/AJEnglish/status/1283068744512811008; and *Al Jazeera*, "Why is the Gulf going nuclear?", Video posted 26 July 2020, see https://www.youtube.com/watch?v=ybdwXo14sQI&list=PLzGHKb8i9vTxodrArxXFPziklfoiqFdC5&index=1, both accessed 29 August 2020.

The WNISR deadline for statistical and major editorial information is 1 July. This year, July and August were particularly rich in nuclear and energy related information. Here are some news items likely to be analyzed in more detail in the WNISR2021, some of which reflect a surprising level of corruption and other illegal activities in the nuclear sector:

- The U.S. International Development Finance Corporation (DFC) lifted its long-standing ban on funding of nuclear energy projects overseas.[21] This makes the DFC one of the few development banks that allow investment in new nuclear projects. The World Bank and the Asian Development Bank (ADB) amongst others do not permit funding of new nuclear power projects.
- The speaker of the Ohio House of Representatives, Larry Householder, was arrested by the U.S. Federal Bureau of Investigation (FBI) on charges of racketeering. Allegedly, 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."[22] As a consequence, in 2019, FirstEnergy's Oak Harbor and Perry reactors were granted generous US$1.3 billion of taxpayer-money support to keep 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.[23]
- The revelation of the massive bribery affair in Ohio came within days of U.S. federal prosecutors in Chicago charging Commonwealth Edison (ComEd) with bribery and a US$200 million fine. ComEd, the largest electric utility in Illinois, paid at least US$1.3 million in contracts, jobs, and other payments to associates of state House Speaker Michael Madigan, a Democrat, and "in return received [US]$150 million in benefits resulting from legislation that relaxed oversight of the utility".[24]
- In a different affair, Steve Byrne, former Vice-President of SCANA—the utility that in 2017 abandoned construction of the V.C. Summer plant in South Carolina—pleaded guilty to fraud charges in federal court. Peter McCoy, U.S. Attorney for South Carolina, told the Federal District Court in Columbia that Byrne "joined a conspiracy with other senior SCANA executives to defraud customers of money and property through… false and misleading statements and omissions." The guilty plea was the result of a three-year investigation by the FBI and prosecutors at the Federal Attorney's Office in Columbia. The fraud charges he pleaded to can carry up to five years in prison. The company had spent over US$9 billion, much of it ratepayer money, prior to folding the project.[25]

21 - *WNN*, "USA lifts nuclear finance ban", 24 July 2020, see https://world-nuclear-news.org/Articles/USA-lifts-nuclear-finance-ban, accessed 24 July 2020.

22 - Justin Gillis, "Opinion—When Utility Money Talks", *New York Times*, 2 August 2020, see https://www.nytimes.com/2020/08/02/opinion/utility-corruption-energy.html, accessed 29 August 2020.

23 - Giulia McDonnell Nieto del Rio, "Powerful Ohio Republican Is Arrested in $60 Million Corruption Scheme", *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.

24 - Akela Lacy, "Energy Companies Have Spent Billions on Projects That Go Nowhere", *The Intercept*, 7 August 2020, see https://theintercept.com/2020/08/07/nuclear-power-energy-utility-bribery-scandal/, accessed 5 September 2020.

25 - John Monk and Joseph Bustos, "Top ex-SCANA official Stephen Byrne pleads guilty in SC nuclear fiasco fraud case", *The State*, 23 July 2020, see https://www.thestate.com/news/local/crime/article244429397.html; and Andrew Brown and Avery G. Wilks, "Former SCANA executive pleads guilty to fraud charges tied to failed SC nuclear project", *Post and Courier*, 23 July 2020, see https://www.postandcourier.com/business/former-scana-executive-pleads-guilty-to-fraud-charges-tied-to-failed-sc-nuclear-project/article_26e23ca8-c50b-11ea-8377-e7b39854212b.html, both accessed 25 July 2020.

- In the aftermath of the ComEd scandal, the company's owner Exelon, operator of the largest nuclear fleet in the U.S., was concerned its attempts to impose legislative change to allow for subsidies for its uneconomic Byron and Dresden plants in Illinois could fail. Exelon CEO Chris Krane stated: "If we can't find... a path to profitability, we will have to shut them down."[26] Three weeks later Kane announced the early closure of the four reactors, the two 33- and 35-year-old units at Byron in September 2021 (although licensed for another 20 years) and the 49 and 50-year-old units at Dresden in November 2021 (licensed for another decade).[27]
- As a result of storm damage incurred on 10 August 2020, the Duane Arnold-1 reactor will not return to service and will instead be permanently closed. It was previously scheduled for closure on 30 October 2020. This is the second reactor closure in the U.S. and the fourth in the world since the beginning of 2020.[28]
- EDF Energy is to close its Hunterston B plant in the U.K. in late 2021, at least two years earlier than planned. Serious graphite cracking and other damage had been identified at the two 44- and 43-year-old Advanced Gas-cooled Reactors (AGRs) in 2018 and the units were shut down over the past two years. Repairs for longer-term operation turned out impossible or too costly.[29].
- The startups of the Franco-German nuclear projects in Finland and France have been delayed for the nth time. While the first EPR started building in Olkiluoto in 2005 and was, at the time, scheduled to deliver power by 2009, "regular electricity generation" is now planned for February 2022[30] (see Finland Focus); the second one in Flamanville started construction in 2007 and was supposed to supply electricity by 2012 but power generation is now not expected before 2023. *Popular Mechanics* concluded: "France's Revolutionary Nuclear Reactor Is a Leaky, Expensive Mess."[31]
- The French Financial Market Authority (AMF) imposed a fine of €5 million (US$6 million) on EDF and a fine of €50,000 (US$60,000) on Henri Proglio, former CEO of EDF for "disseminating false information" on the Hinkley Point C project in the U.K. The AMF ruled that by claiming in a news release of 8 October 2014 that earlier agreements remained "unchanged", when there had in fact been "significant changes to the financing plan by

26 - Jeff St. John, "ComEd Bribery Scandal Clouds Picture for Exelon's Illinois Nuclear Plants", *GreenTechMedia*, 4 August 2020, see https://www.greentechmedia.com/articles/read/comed-bribery-scandal-affects-exelons-illinois-nuclear-plants-ratemaking-policy, accessed 29 August 2020.

27 - *WNN*, "Exelon announces early shutdown of four Illinois reactors: Corporate", 27 August 2020, see https://world-nuclear-news.org/Articles/Exelon-announces-early-shutdown-of-four-Illinois-r, accessed 29 August 2020.

28 - WNISR, "Storm Damage Prompts Early Closure of Duane Arnold Nuclear Reactor in the U.S.", 26 August 2020, see https://www.worldnuclearreport.org/Storm-Damage-Prompts-Early-Closure-of-Duane-Arnold-Nuclear-Reactor-in-the-U-S.html, accessed 30 August 2020.

29 - Severin Carrell and Jillian Ambrose, "Scottish nuclear power station to shut down early after reactor problems", *The Guardian*, 27 August 2020, see http://www.theguardian.com/uk-news/2020/aug/27/hunterston-scottish-nuclear-power-station-to-shut-down-early-after-reactor-problems, accessed 29 August 2020.

30 - TVO, "OL3 EPR regular production of electricity starts in February 2022", 28 August 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprregularproductionofelectricitystartsinfebruary2022.html, accessed 4 September 2020. This latest announcement happened after the editorial deadline for the main body of this report.

31 - Caroline Delbert, "France's Revolutionary Nuclear Reactor Is a Leaky, Expensive Mess", *Popular Mechanics*, 3 August 2020, see https://www.popularmechanics.com/science/energy/a33499619/france-nuclear-reactor-epr-expensive-mess/, accessed 5 August 2020.

guaranteed debt, EDF had disseminated false information likely to set the share price at an abnormal or artificial level".[32]

While the nuclear industry was struggling with COVID-19 cases, dramatically reduced workforces in operating plants and facilities under construction, the renewable energy industry apparently suffered much less and shorter impacts of the pandemic. It is obvious that operating solar plants or wind farms need significantly less maintenance by fewer workers than a nuclear facility. Also, the construction of new generating facilities requires less workers on-site at any given time in the renewable sector than in the case of nuclear. New renewables (excluding hydro) come in much smaller units, and therefore appear as a whole significantly more resilient than in the nuclear sector.

- → The lowest ever commercial offer for solar electricity was issued in Portugal in August 2020 at €11.14/MWh (US$13.2/MWh), just below a July 2020 bid in Abu Dhabi at US$13.5/MWh (see Figure 25).[33]
- → Wind and solar electricity generation increased by 19 percent year-on-year in the first seven months of 2020 across the Big-5 power markets (France, Germany, Italy, Spain, U.K.) with solar power generation at an all-time high[34], while nuclear generation was on the decline in many nuclear countries around the world.
- → China's newly installed solar capacity has recovered quickly after a year-on-year decline due to COVID-19 in the first quarter of 2020, and the half-year result is even slightly above 2019 (11.5 GW vs. 11.4 GW).[35]
- → In spite of COVID-19, wind power capacity additions in the first half of 2020 exceeded 2019-results significantly in major markets including the E.U., Japan and the U.S. where added capacity more than doubled to over 4 GW.[36]
- → In spite of COVID-19, global investment in new renewables increased year-on-year in the first half of 2020 by 5 percent to an estimated US$132 billion, driven by the tripling of investments in off-shore wind to US$35 billion.[37]

And as a consequence of some of the development mentioned above:

- → As of mid-2020, energy consumption in the U.S. fell to its lowest level in 30 years; 19 energy companies, mostly oil and gas, had filed for bankruptcy in the U.S. in these six

32 - AMF, "The AMF's Enforcement Committee fines EDF and its former Chairman and Chief Executive Officer for disseminating false information about the project to build a nuclear plant at Hinkley Point in the United Kingdom", Autorité des Marchés Financiers, 30 July 2020, see https://www.amf-france.org/en/news-publications/news-releases/enforcement-committee-news-releases/amfs-enforcement-committee-fines-edf-and-its-former-chairman-and-chief-executive-officer, accessed 30 August 2020.

33 - Emiliano Bellini, "Portugal's second PV auction draws world record low bid of $0.0132/kWh", *PV Magazine*, 24 August 2020, see https://www.pv-magazine.com/2020/08/24/portugals-second-pv-auction-draws-world-record-low-bid-of-0-0132-kwh/, accessed 5 September 2020.

34 - *PiE*, "RES tracker: July wind, solar up 19% on year", 10 August 2020.

35 - *Taiyang News*, "China Reports To Have Grid Connected 11.52 GW New Solar PV Capacity In H1/2020 Taking Cumulative Capacity To 216 GW: NEA", 31 July 2020, see http://taiyangnews.info/markets/nea-china-installed-11-52-gw-solar-pv-in-h12020/, accessed 29 August 2020.

36 - Bruno Brunetti, "Despite COVID-19 disruptions, wind additions up 6% Y/Y in H1 2020 across major markets, with US and Europe leading" Tweet, *S&P Global Platts*, 24 August 2020, see https://twitter.com/bbrunettienergy/status/1297921898848956418, accessed 29 August 2020.

37 - BNEF, "Colossal Six Months for Offshore Wind Support Renewable Energy Investment in First Half of 2020", BloombergNEF, 13 July 2020, see https://about.bnef.com/blog/colossal-six-months-for-offshore-wind-support-renewable-energy-investment-in-first-half-of-2020/, accessed 30 August 2020.

months.[38] (Already in April 2020, for the first time ever, oil was traded at negative prices and producers paid shippers to get rid of it).

- For the first time ever, the world's coal power plant fleet ran at less than half of its capacity (47 percent) for six months in a row (January to June 2020) on average with China at 45 percent, the EU at 24 percent, India at 51 percent and the U.S. at 32 percent. Renewables generated an estimated 10 percent. However, in spite of the significant impact of COVID-19 on electricity consumption and the rise of renewables, coal use dropped "only" by 8 percent year-on-year over the first half of 2020, while it needs to fall 13 percent annually to reach the +1.5°C climate goal by 2050.[39]

This is quite an amazing list of developments and revelations in just two months. In WNISR2018, we started to assess the performance of the French nuclear sector reactor-by-reactor and WNISR2019 provided a full picture of the year 2018. WNISR2020 offers an update to that analysis. The *average* outage (at zero power, not including reduced output) per unit for the 58 French reactors has increased by 10 percent in 2019, exceeding three months (96.2 days) per year, totaling 5,580 reactor-days, up 500 days over the previous year (see France Focus). In the previous editions, we were wondering about EDF's declaration of planned vs. unplanned outages and were intrigued about the principle 'once planned, always planned'. Therefore, we decided to analyze scheduled vs. real restarts and the result is staggering, with an average of 40 percent increase between scheduled vs. real outage times. EDF, the largest nuclear operator in the world, has entirely lost control of outage planning.

In Japan, no new units have been restarted since mid-2018—four restarted in the first half of 2018—and there are still only nine operating reactors in the country. As of mid-2020, 24 reactors remain in Long-Term Outage (LTO) with uncertain prospects for restart, which is still highly controversial amongst the Japanese public (see Japan Focus).

Small Modular Reactors or SMRs have made little progress ever since the first WNISR assessment in 2015, as this edition's update concludes: "delays, poor economics, and the increased availability of low-carbon alternatives at rapidly decreasing cost plague these technologies as well, and there is no need to wait with bated breath for SMRs to be deployed" (see Small Modular Reactors).

The WNISR's overview of decommissioning of closed reactors identifies few major developments. While eight additional reactors have been closed since WNISR2019, only one more reactor finished the technical decommissioning process, bringing the total to 20 units of a total of 189 closed reactors in the world. The detailed analysis is in the Decommissioning Status Report.

It has become a challenge to keep the traditional Nuclear Power vs. Renewable Energy chapter up to date as developments have accelerated to a point that becomes difficult to account for in an annual report. It provides a global comparative overview on investment, deployment, production of non-hydro renewables vs. nuclear power as well some country specific analysis, including on China, India, the EU, and the U.S.

38 - Johnna Crider, "COVID-19 Bankrupts 19 Energy (Oil & Gas) Companies", *CleanTechnica*, 5 August 2020, see https://cleantechnica.com/2020/08/05/covid-19-bankrupts-19-energy-oil-gas-companies/, accessed 7 August 2020.

39 - Dave Jones, Euan Graham and Pete Tunbridge, "Wind and Solar Now Generate One-Tenth of Global Electricity—Global half-year electricity analysis", Ember, 13 August 2020, see https://ember-climate.org/project/global-electricity-h12020/, accessed 30 August 2020.

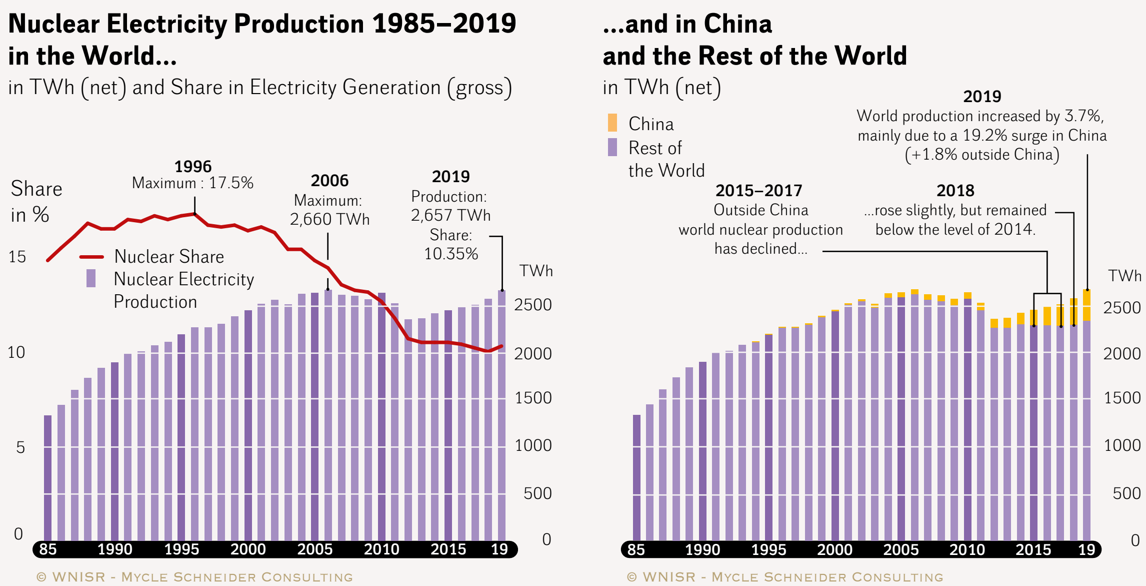
GENERAL OVERVIEW WORLDWIDE

PRODUCTION AND ROLE OF NUCLEAR POWER

In 2019, the world nuclear fleet generated 2,657 net terawatt-hours (TWh or billion kilowatt-hours) of electricity[40], a 3.7 percent increase over the previous year— half of this rise is due to China's nuclear output increasing by over 19 percent—and only 3 TWh below the historic peak in 2006 (see Figure 1). Without China, global nuclear power generation slightly increased (+1.8 percent). The numbers illustrate that China continues to dominate the key indicators in nuclear statistics.

Nuclear energy's share of global commercial gross electricity generation in 2019 has marked a break in its slow but steady decline from a peak of 17.5 percent in 1996, with a 0.2 percentage-point increase over the 10.15 percent in 2018 to 10.35 percent in 2019. However, with non-hydro renewables' strongest annual growth on record, "their share in power generation (10.4 percent) also surpassed nuclear for the first time", as BP notes in their annual statistical review.[41]

Figure 1 · Nuclear Electricity Generation in the World... and China



Sources: WNISR, with BP, IAEA-PRIS, 2020[42]

40 - 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.

41 - BP, "Statistical Review of World Energy 2020: a pivotal moment", 17 June 2020, see https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-statistical-review-of-world-energy-2020-published.html, accessed 26 June 2020.

42 - BP stands for BP plc; WNISR for World Nuclear Industry Status Report.

The nuclear contribution to commercial primary energy generation remained stable at 4.3 percent. It has been around this level since 2014.[43]

In 2019, nuclear generation increased in 19 countries of the 31 countries operating commercial reactors, declined in eight, and remained stable in four.[44] A remarkable eight countries (Argentina, Brazil, China, Finland, Hungary, India, Russia, U.S.) achieved their largest ever nuclear production. As only two of these countries started up new units (China and Russia), the others either restarted reactors after long outages, sometimes involving significant overhaul including an increase in capacity or improved their performance through better plant management.

The following noteworthy developments for the year 2019 illustrate the continuous volatile operational situation of the individual national reactor fleets (see country-specific sections for details):

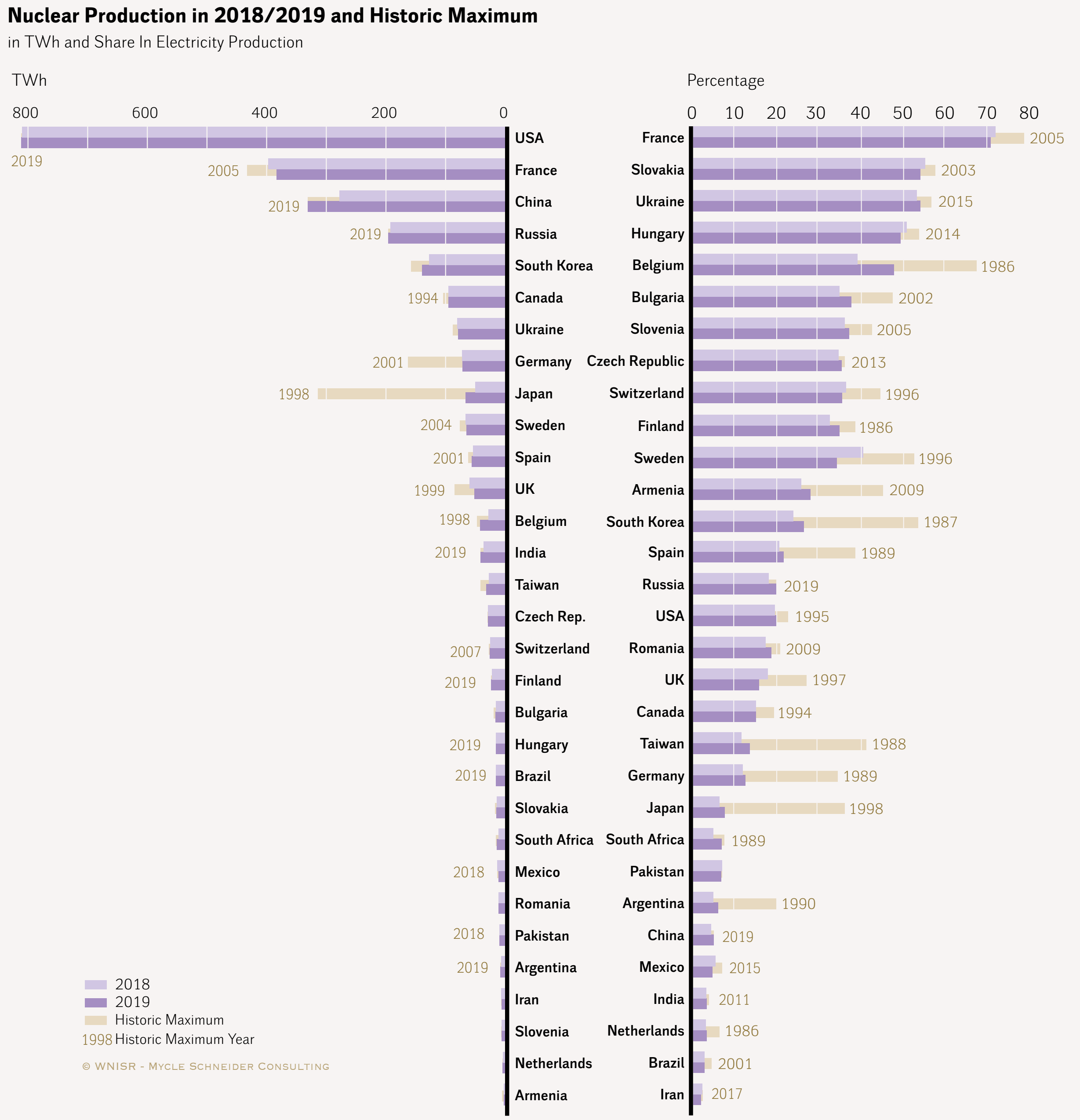
- **Argentina** boosted output by almost 23 percent after one of their three reactors (Embalse) returned to service following a four-and-a-half-year refurbishment-outage.
- **Belgium**'s nuclear generation increased by 52 percent after a 32-percent plunge in 2018 due to the extension of outages for maintenance, repair and upgrade.
- **China** started up only two new units after having connected seven reactors to the grid in 2018, which helped increase output by 19.2 percent in 2019.
- **France**'s nuclear generation decreased by 3.4 percent, remaining for the fourth year in a row below the 400 TWh mark. In the 15 years between 2001 and 2015, this had happened only once, in the crisis year 2009 (see France Focus).
- **India** increased generation by just over 15 percent, following several years of stagnation, achieving an annual load factor of almost 74 percent, compared to a lifetime load factor of 60 percent.
- **Japan**, that had restarted four more units in 2018, bringing the total of operating reactors to nine, did not restart any additional units but boosted output by one third in 2019.
- **Russia** reached a new peak in nuclear electricity generation and overtook China in the number of startups during the year (three vs. two).
- **South Korea** increased nuclear production by 9.2 percent following a 10-percent decline in 2018. In spite of the grid connection of a new reactor in April 2019, the country did not return to 2017 generation levels.
- **South Africa** increased generation by 28.4 percent but could not make up for the 29.8 percent drop in the previous year.
- The **U.K.** nuclear generation decreased by 13.7 percent, due to repeatedly extended, long outages of some its reactors.
- The **U.S.** improved its 2018, all-time highest nuclear electricity generation by another 1.3 TWh (0.2 percent). While the increase remains marginal, it is a remarkable achievement as two more reactors were closed during the year (Pilgrim-1 in April and Three-Mile-

43 - Ibidem. Natural gas consumption increased by 2 percent, oil consumption by 0.9 percent, while coal consumption fell by 0.6 percent to its lowest share in primary energy consumption in 16 years. China accounted for more than three quarters of the modest 1.3 percent net global primary-energy consumption-growth, while the U.S. and Germany registered the largest declines.

44 - Less than 1 percentage point variation from the previous year.

Island-2 in September) and no new ones were started up since 2016. With the average age hitting 40 years in 2020, the productivity of the U.S. reactor fleet is astounding and quite contrary to the difficulties with ageing issues in other countries.[45]

Figure 2 · Nuclear Electricity Generation and Share in Global Power Generation



Sources: IAEA-PRIS, and national sources for Germany and Switzerland, 2020

45 - This report does not discuss the question whether this performance is at least partially due to potentially lower safety and security requirements than practiced in other nuclear countries. But the difference in productivity with countries like France and the U.K. is indeed astounding. While the U.S. has achieved a load factor of over 90 percent in 2019, France and the U.K. remained below 70 percent, precisely because of extensive refurbishment outages.

With remarkable stability, just as in previous years, in 2019, the "big five" nuclear generating countries—by rank, the U.S., France, China, Russia and South Korea—generated 70 percent of all nuclear electricity in the world (see Figure 2, left side). In 2002, China held position 15, in 2007 it was tenth, before reaching third place in 2016. With another 15 reactors under construction, China will likely overtake France within the next few years. In the meantime, the two top countries alone, the U.S. and France, accounted for 45 percent of global nuclear production in 2019.

In many cases, even where nuclear power generation has increased in the past, the addition is not keeping pace with overall increases in electricity production, leading to a nuclear share below the respective historic maximum (see Figure 2, right side). Only two countries, China and Russia, reached new historic peak shares of nuclear in their respective power mix, both at small increases, +0.7 percentage points for China (reaching a share of 4.9 percent) and +1.8 percentage points for Russia (attaining 19.7 percent.)

However, in 2019, there were 12 countries that increased their nuclear share—three times as many as in 2018—and 13 remained at a constant level (change of less than 1 percentage point), while six decreased their nuclear shares.

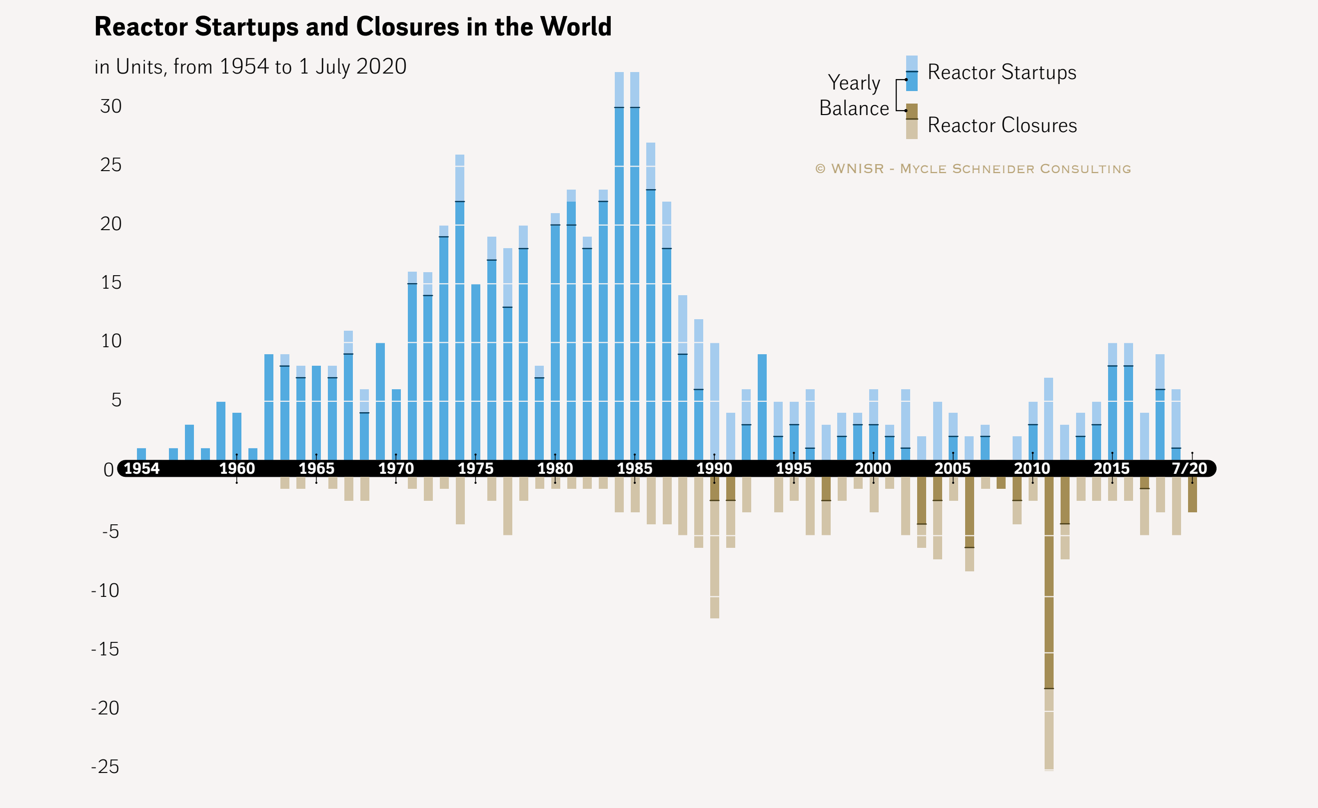
OPERATION, POWER GENERATION, AGE DISTRIBUTION

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[46] outweighed the number of startups. The 1991–2000 decade produced far more startups than closures (52/30), while in the decade 2001–2010, startups did not match closures (32/37). Furthermore, after 2000, it took a whole decade to connect as many units as in a single year in the middle of the 1980s (see Figure 3). Between 2011 and mid-2020, the startup of 58 reactors—of which 35 (60 percent) in China alone—outpaced by two only the closure of 56 units over the same period. As there were no closures in China over the period, the 56 closures outside China were only matched by 23 startups, a startling decline by 33 units over the period. (See Figure 4).

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, while three units were closed, of which two in Russia and one in the U.S. 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 (see Figure 4).

46 - 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 latest power generation.

Figure 3 · Nuclear Power Reactor Grid Connections and Closures in the World



Sources: WNISR, with IAEA-PRIS, 2020

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 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.)

Not a single new unit was connected to the world's power grids in the first half of 2020[47], including in China, where no unit was started up since mid-2019.[48] It is not since the Fukushima disaster in 2011 that there has not been a single startup in China for a full year.[49]

Three reactors were closed in 2020 by mid-year, the two oldest units in France (Fessenheim-1 and -2) and one in the U.S. (Indian Point-2).

As of mid-2020, 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. That is a significant drop of 11 compared to mid-2019). The IAEA is counting four less "operating" units in Japan than in mid-2019 with the four Fukushima Daini reactors finally considered closed.[50] WNISR has considered them closed since 2012, as the probability for restart were virtually zero with

47 - Two units started up in August 2020, one in China and one in the UAE.

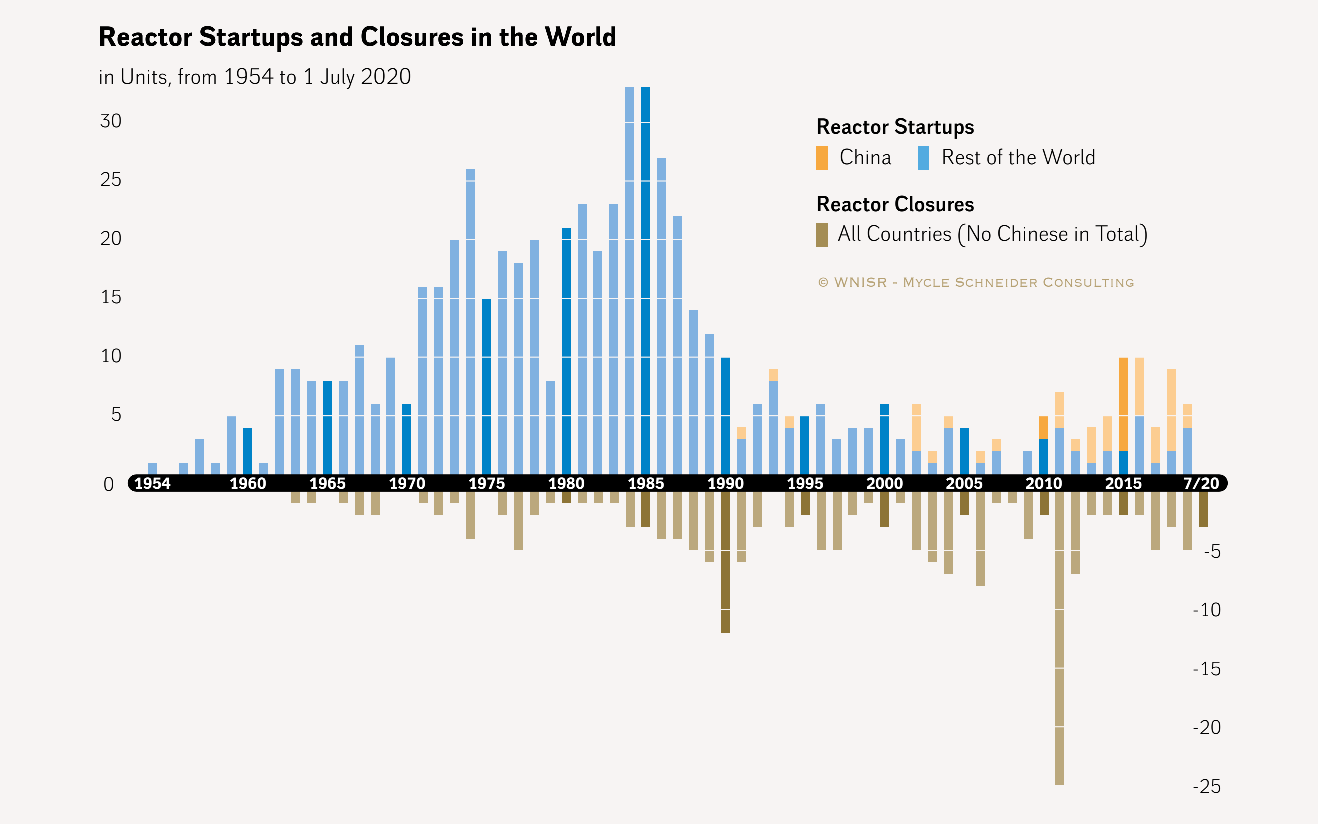
48 - Tianwan-5 was connected to the grid on 8 August 2020, see WNISR, "First Reactor Grid Connection in the World in 2020—in China", 13 August 2020, see https://www.worldnuclearreport.org/First-Reactor-Grid-Connection-in-the-World-in-2020-in-China.html, accessed 22 August 2020.

49 - Quinshan 2-4 was connected to the grid on 25 November 2011 followed by Ningde-1 on 28 December 2012.

50 - IAEA, "Power Reactor Information System", International Atomic Energy Agency, Undated, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, accessed 22 August 2020.

their location in the middle of the exclusion zone, at 15 km distance of the Fukushima Daiichi disaster site. No nuclear electricity was generated in Japan between September 2013 and August 2015, and as of 1 July 2020, only nine reactors were operating (see Japan Focus), just as in mid-2019. Nuclear plants provided only 7.5 percent of the electricity in Japan in 2019.

Figure 4 · Nuclear Power Reactor Grid Connections and Closures – The Slowing China Effect



Sources: WNISR, with IAEA-PRIS, 2020

The WNISR keeps reiterating its call for an appropriate reflection in world nuclear statistics of the unique situation in Japan. The attitude taken by the IAEA, the Japanese Government, utilities, industry and many research bodies as well as other Governments and organizations to continue considering the entire stranded reactor fleet in the country as "in operation" or "operational" is misleading.

The IAEA actually does have a reactor-status category called "Long-term Shutdown" or LTS.[51] 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 zero reactors anywhere in the LTS category.

The IAEA criteria are vague and hence subject to arbitrary 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

51 - See IAEA Glossary, at www.iaea.org/pris/Glossary.aspx, accessed 1 July 2016.

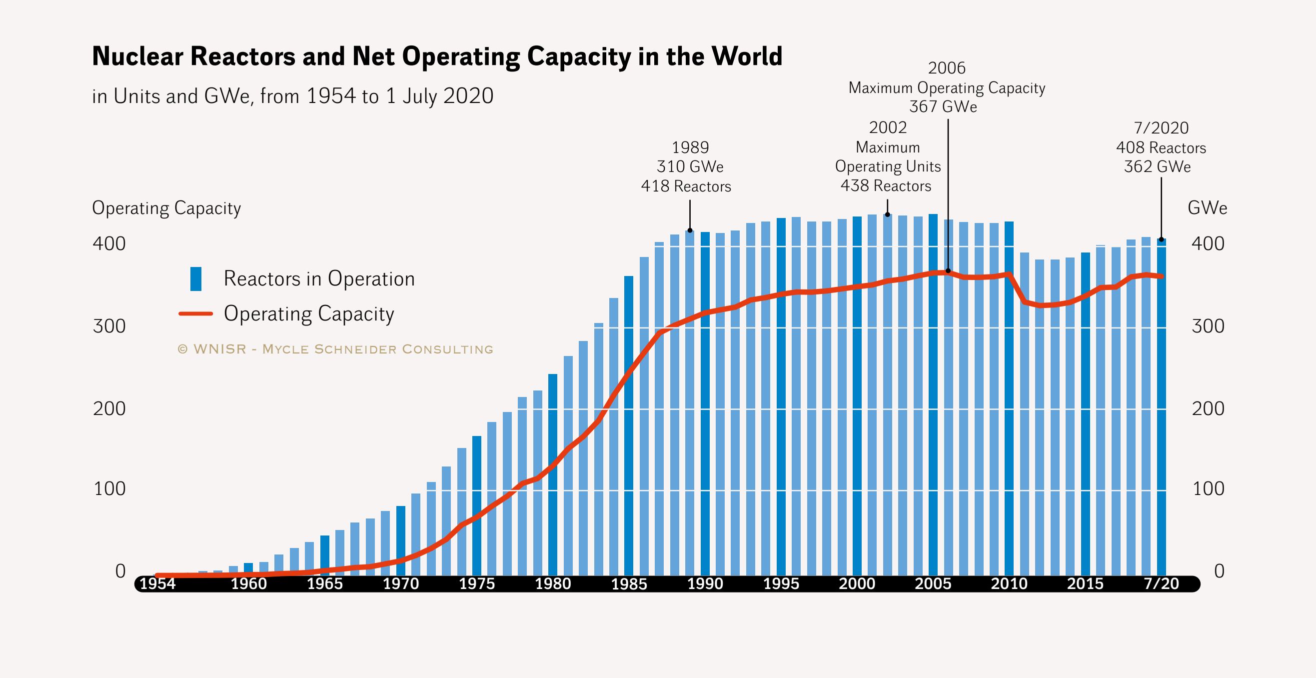
with a simple definition, based on empirical fact, without room for speculation: "Long-term Outage" or LTO. Its definition:

> 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 2020, leads to classifying 31 units in LTO—all considered "in operation" by the IAEA—three more than in WNISR2019, of which 24 in Japan (no change) and one in China (China Experimental Fast Reactor – CEFR). Three units entered the category in the U.K. (Hunterston-B1, Dungeness-B1 and -B2), one each in India (Madras-1) and South Korea (Hanbit-3, with Hanbit-4 remaining in LTO). One reactor in Canada (Darlington-2) restarted from LTO since mid-2019. One unit in Taiwan (Chinshan-2) moved from LTO to closed.

Figure 5 · World Nuclear Reactor Fleet, 1954–2020



Sources: WNISR, with IAEA-PRIS, 2020

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

As of 1 July 2020, a total of 408 nuclear reactors were operating in 31 countries, down nine units from the situation in mid-2019[52]. The current world fleet has a total nominal electric net capacity of 362 GW, down by 7.5 GW (–2.1 percent) from one year earlier. The number of operating reactors remains by 10 below the figure reached in 1989 and by 30 below the 2002

52 - +2 startups +1 restart –5 new LTOs –7 closures.

peak (see Figure 5). With three reactors closed in the first half of 2020 but none started up, and four more units in LTO, the number of operating units and their installed capacity has also declined since the end of 2019.

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. Thus, in 1989, the average size of an operational nuclear reactor was about 740 MW, while that number has increased to almost 890 MW in 2020) and technical alterations raising capacity at existing plants resulting in larger electricity output, a process known as uprating.[53] In the U.S. alone, the Nuclear Regulatory Commission (NRC) has approved 164 uprates since 1977. The cumulative approved uprates in the U.S. total 7.9 GW, the equivalent of eight large reactors.[54] No additional uprates were approved since April 2018 and there are no pending applications as of mid-2020. Four additional applications were expected in 2019 but did not materialize.

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.

OVERVIEW OF CURRENT NEW-BUILD

As of 1 July 2020, 52 reactors are considered as under construction. After falling for five years in a row, there are six more units than WNISR reported a year ago, but 17 fewer than in 2013 (five of those units have subsequently been abandoned).

Three in four reactors are built in Asia and Eastern Europe. In total, 17 countries are building nuclear plants, one more than reported in WNISR2019, with Iran restarting construction on Bushehr-2 (see Table 1). However, only four countries have construction ongoing at more than one site (see Annex 5, Figure 6 for details).

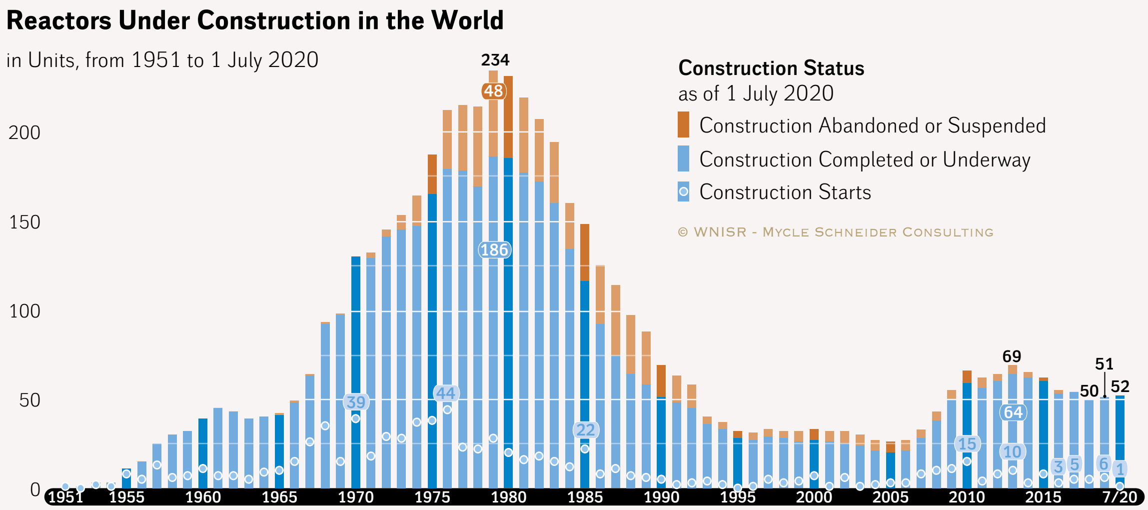
Four new construction sites were launched in China, including two CAP1400 units at Shidao-Bay where building started in April and October 2019 respectively, but that were not being taken into account in WNISR2019 (for Unit 1) and have not been reported by IAEA-PRIS as of mid-August 2020. One construction start took place in the U.K. with Hinkley Point C-2. The only construction start reported in the first half of 2020 was Akkuyu-2 in Turkey.

The figure of 52 reactors listed as under construction by mid-2020 compares 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 6). The year 2005, with 26 units under construction, marked a record low since the early nuclear age in the 1950s. Compared to the situation described a year ago, the total capacity of units under construction in the world as of mid-2020 increased by 8.9 GW to 53.5 GW, with an average unit size of 1,028 MW.

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

54 - U.S.NRC, "Approved Applications for Power Uprates", U.S. Nuclear Regulatory Commission, Updated 2 April 2019, see http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 22 August 2020.

Figure 6 · Nuclear Reactors "Under Construction" in the World (as of 1 July 2020)



Sources: WNISR, with IAEA-PRIS, 2020

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 plant under construction since 2012 has actually two reactors on the site and is therefore counted as two units as of WNISR2020.

Table 1 · Nuclear Reactors "Under Construction" (as of 1 July 2020)[55]

Country	Units	Capacity (MW net)	Construction Start	Grid Connection	Units Behind Schedule
China	15	13 842	2012 - 2019	2020 - 2025	6
India	7	4 824	2004 - 2017	2020 - 2023	5
South Korea	4	5 360	2012 - 2018	2020 - 2024	4
UAE	4	5 380	2012 - 2015	2020 - 2023	4
Russia	3	3 315	2010 - 2019	2021 - 2023	1
Bangladesh	2	2 160	2017 - 2018	2023 - 2024	0
Belarus	2	2 218	2013 - 2014	2020 - 2021	2
Pakistan	2	2 028	2015 - 2016	2021	1
Slovakia	2	880	1985 - 1985	2020 - 2021	2
Turkey	2	2 228	2018 - 2020	2024 - 2025	1
UK	2	3 260	2018 - 2019	2025 - 2026	0
USA	2	2 234	2013	2021 - 2022	2
Argentina	1	25	2014	2021	1
Finland	1	1 600	2005	2021	1
France	1	1 600	2007	2022	1
Iran	1	1 196	1976	2024	1
Japan	1	1 325	2007	?	1
Total	**52**	**53 475**	**1976 - 2020**	**2020 - 2026**	**33**

Sources: Various, Compiled by WNISR, 2020

Notes: This table does not contain suspended or abandoned constructions.
This table includes construction of two CAP1400 reactors at Rongcheng/Shidaowan, although their construction has not been officially announced (see China Focus). At Shidao Bay, the plant under construction since 2012 has actually two reactors on the site and is therefore counted as two units as of WNISR2020.

55 - For further details, see Annex 5.

CONSTRUCTION TIMES

Construction Times of Reactors Currently Under Construction

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

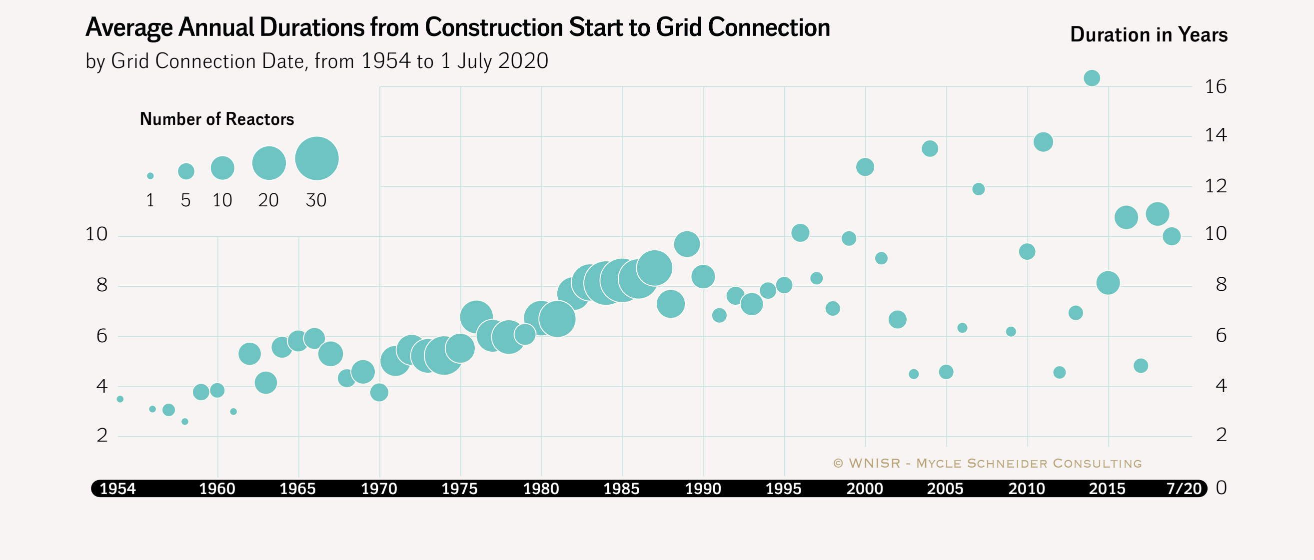
- As of 1 July 2020, for the 52 reactors being built an average of 7.3 years have passed since construction start—an increase of more than six months compared to the mid-2019 average—and many remain far from completion.
- *All* reactors under construction in at least 10 of the 17 countries have experienced mostly year-long delays. At least 33 (64 percent) of the building projects are delayed. Most of the units which are nominally being built on-time were begun within the past three years or have not yet reached projected startup dates, making it difficult to assess whether or not they are on schedule. Particular uncertainty remains over construction sites in Bangladesh, China, Russia and the U.K.
- Of the 33 reactors clearly documented as behind schedule, at least 12 have reported *increased* delays and four have reported *new* delays over the past year.
- WNISR2018 noted a total of 14 reactors scheduled for startup in 2019. At the beginning of 2019, two of these were already connected to the grid in late 2018, ten were still scheduled for startup during the year, in addition to four reactors previously scheduled for 2018, while the others were delayed at least into 2020. Only six made it in 2019.
- Construction start of two projects dates back 35 years, Mochovce-3 and -4 in Slovakia, and their startup has been further delayed, currently to 2020–2021. Bushehr-2 originally started construction in 1976, that is 44 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2024.
- Five reactors have been listed as "under construction" for a decade or more: the Prototype Fast Breeder Reactor (PFBR) in India, the Olkiluoto-3 (OL3) reactor project in Finland, Shimane-3 in Japan, the French Flamanville-3 (FL3) and Leningrad 2-2 in Russia. The Finnish project has been further delayed this year, grid connections of the French and Indian units are likely to be postponed again, 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. As the U.K.'s Hinkley Point C (HPC) project illustrates, a significant share of investment and work was carried out long before even entering the official construction phase (see United Kingdom Focus).

Construction Times of Past and Currently Operating Reactors

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 7 illustrates, construction times of reactors completed in the 1970s and 1980s were quite homogenous, while in the past two decades they have varied widely.

Figure 7 · Average Annual Construction Times in the World



Sources: WNISR, with IAEA-PRIS, 2020

The nine units completed in 2018–2019 by the Chinese nuclear industry took on average 7.6 years to build, while the five Russian projects took a mean 16 years from first construction start to grid connection, with Rostov-4 taking 35 years from construction start to finally generate power (see The Construction Saga of Rostov Reactors 3 and 4).

The case of the twin "floating" reactors Akademik-Lomonosov is particularly interesting. These are small 30-MW reactors and they were meant to demonstrate a precursor to 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 the two-year period (with the exception of Rostov-4) and about four 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 and that it would complete five additional floating nuclear plants by 2015[56]. The first one finally started up only in December 2019. Not surprisingly, the "nuclear barge" has become more expensive, from an initial estimate of around 6 billion rubles (US$$_{2007}$232 million)[57] to at least 37 billion rubles as of 2015 (US$$_{2015}$740 million),[58] or close

56 - 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.

57 - *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.

58 - 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.

to US$11,600 per installed kilowatt, significantly more expensive than the most expensive Generation III reactors.[59]

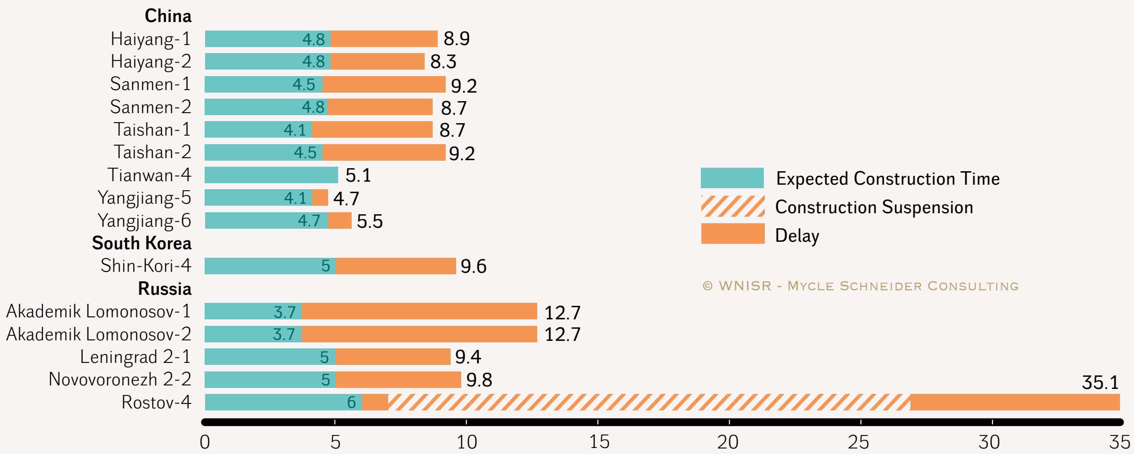
The mean time from construction start to grid connection for the six reactors started up in 2019 was 9.9 years, improving from 10.9 years in 2018, confirming the trend towards an average of around a decade. By mid-2020, no new unit had started up in the year anywhere in the world.

Over the two years 2018 and 2019, there is only one unit that started up on-time, and that is Tianwan-4 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 Yangjiang-5 and -6 were completed with minor delays in 4.7 and 5.5 years respectively. These are ACPR1000 reactors, designed by China General Nuclear Corp. (CGN) that it claims contain at least ten improvements making them a Gen III design.[60] Leaving the epic Rostov-4 case aside, the other six units that started up in China (four AP1000s, two EPRs), the two large reactors in Russia (Leningrad 2-1 and Novovoronezh 2-2) and the one in South Korea (Shin-Kori-4) all experienced years-long delays and roughly doubled their respective planned construction time to 8.3–9.8 years, while the two floating reactors took with 12.7 years about four times as long to complete as planned (see Figure 8).

Figure 8 · Delays for Units Started Up 2018–2019

Expected vs. Real Duration from Construction Start to Grid Connection for Startups 2018–2019

in Years



Sources: WNISR with IAEA-PRIS, 2020

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.

59 - The current cost estimate of the Flamanville-3 EPR (excl. financing costs) is about US$9,000/kW (see France Focus).

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

The longer-term perspective confirms that short construction times remain the exceptions. Nine countries completed 63 reactors over the past decade—of which 37 in China alone—after an average construction time of 10 years (see Table 2).

Table 2 · Duration from Construction Start to Grid Connection 2010–2019

Construction Times of 63 Units Started-up 2010–2019				
Country	Units	Construction Time (in Years)		
		Mean Time	Minimum	Maximum
China	37	6.0	4.1	11.2
Russia	10	20.3	8.1	35.1
South Korea	6	6.0	4.1	9.6
India	4	10.4	7.2	14.2
Pakistan	3	5.4	5.2	5.6
Argentina	1	33.0	33.0	
Iran	1	36.3	36.3	
USA	1	43.5	43.5	
World	**63**	**10.0**	**4.1**	**43.5**

Sources: Various, Compiled by WNISR. 2020

CONSTRUCTION STARTS & CANCELLATIONS

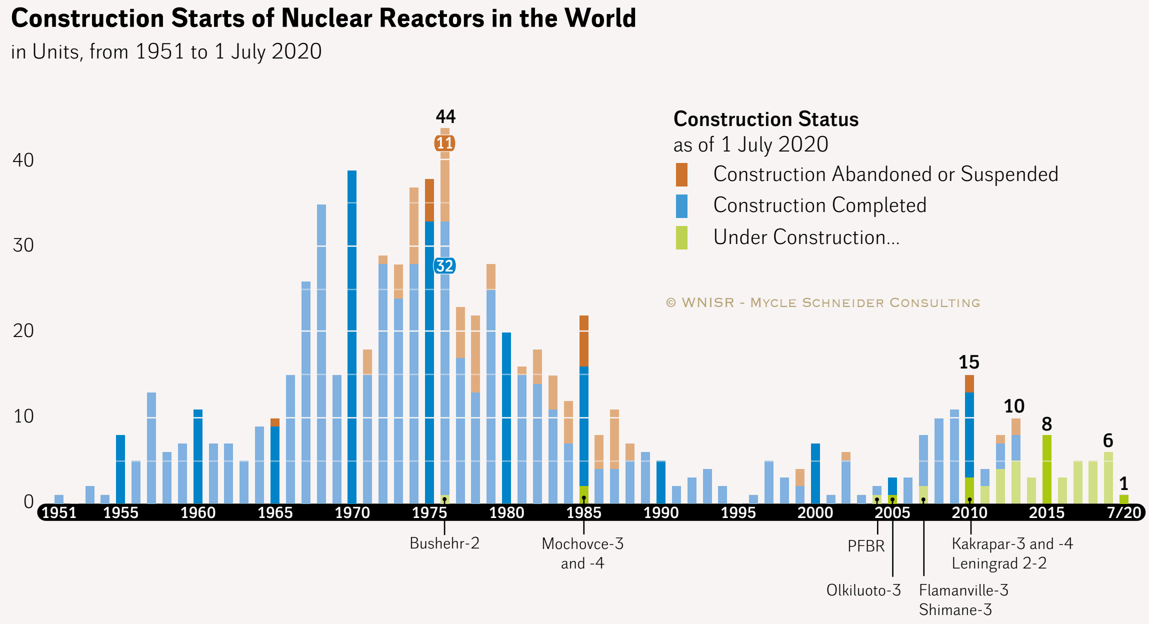
The number of annual construction starts[61] in the world peaked in 1976 at 44, of which 12 projects were later abandoned. In 2010, there were 15 construction starts—including 10 in China—the highest level since 1985 (see Figure 9 and Figure 10). That number dropped to five each in 2017 and 2018. In 2019, WNISR accounts for six construction starts, four in China and one each in Russia and the U.K. In the first half of 2020, only the Akkuyu-2 construction was kicked off. Like most of the construction projects of the past decades, it was Government owned or controlled companies that launched all of the reactors over the past 18 months.

Seriously affected by the Fukushima events, China did not start any construction in 2011 and 2014 and began work only on eight 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 in 2019 (see Figure 10). While this increase could mean a restart of commercial reactor building in China, for the time being, the level remains 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 mid-2020, China had 47 units with 45.5 GW operating and 15 units with 13.8 GW under construction, far from the original target.

Over the decade 2010–2019, construction began on 67 reactors in the world, of which five have been abandoned. With 31 units, half of the building projects that were continued are located in China. As of mid-2020, only 18 of the 62 units have started up, while 44 remain under construction.

61 - 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 9 · Construction Starts in the World



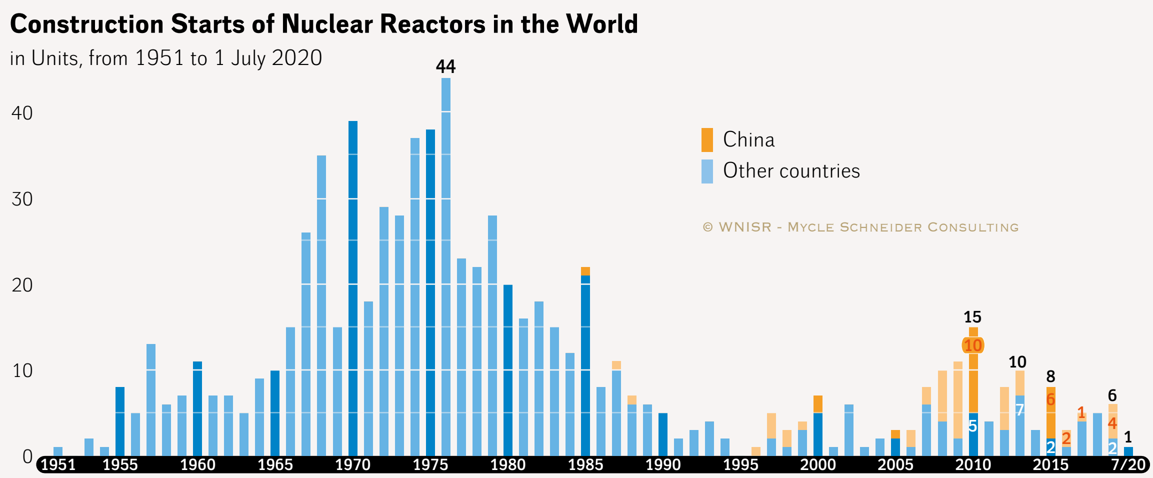
Sources: WNISR, with IAEA-PRIS, 2020

Notes:

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

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

Figure 10 · Construction Starts in the World/China



Sources: WNISR, with IAEA-PRIS, 2020

Notes:

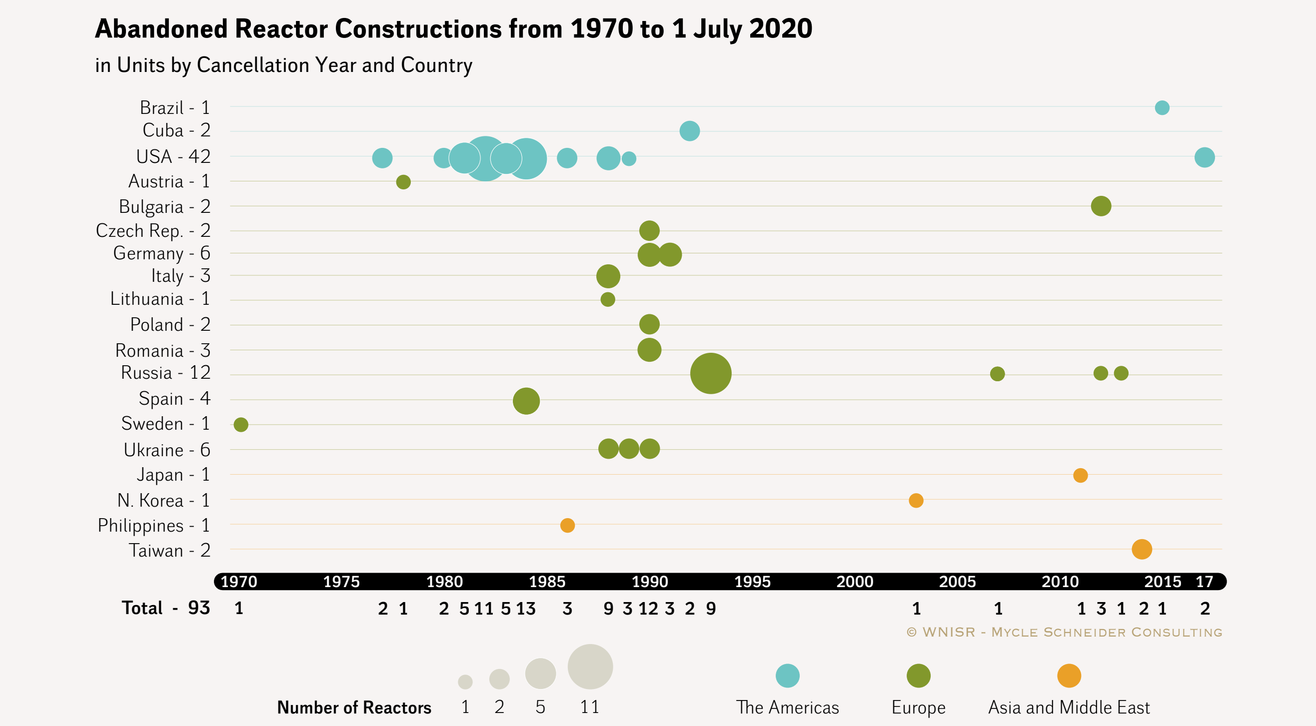
Construction of Bushehr-2, started in 1976, was considered abandoned in previous versions of this figure. As construction was restarted in 2019, it now appears as "Under Construction".

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

Past experience shows that simply 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 abandonment of the two V.C. Summer units at the end of July 2017 after four years of construction and following multi-billion-dollar investment is only the latest example in a long list of failed nuclear power plant projects.

French Alternative Energies & Atomic Energy Commission (CEA) statistics through 2002 indicate 253 "cancelled orders" in 31 countries, many of them at an advanced construction stage (see also Figure 11). The United States alone accounted for 138 of these order cancellations.[62]

Figure 11 · Cancelled or Suspended Reactor Constructions



Sources: WNISR, with IAEA-PRIS, 2020

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

Of the 773 reactor constructions launched since 1951, at least 93 units—one less than in WNISR2019 as Bushehr-2 restarted construction in 2019 after 40 years of suspension—in 19 countries had been abandoned as of 1 July 2020. This means that 12 percent or one in eight nuclear constructions have been abandoned in the course of things. The decade 2010–2019 shows an abandoning rate of one-in-thirteen—as five in 67 building sites officially started during that period were later given up at various stages of advancement.

Close to three-quarters (66 units) of all projects cancelled after official construction start were in four countries alone—the U.S. (42), Russia (12), Germany and Ukraine (six each). Some

62 - 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.

units were actually 100 percent completed—including Kalkar in Germany and Zwentendorf in Austria—before the decision was taken not to operate them.

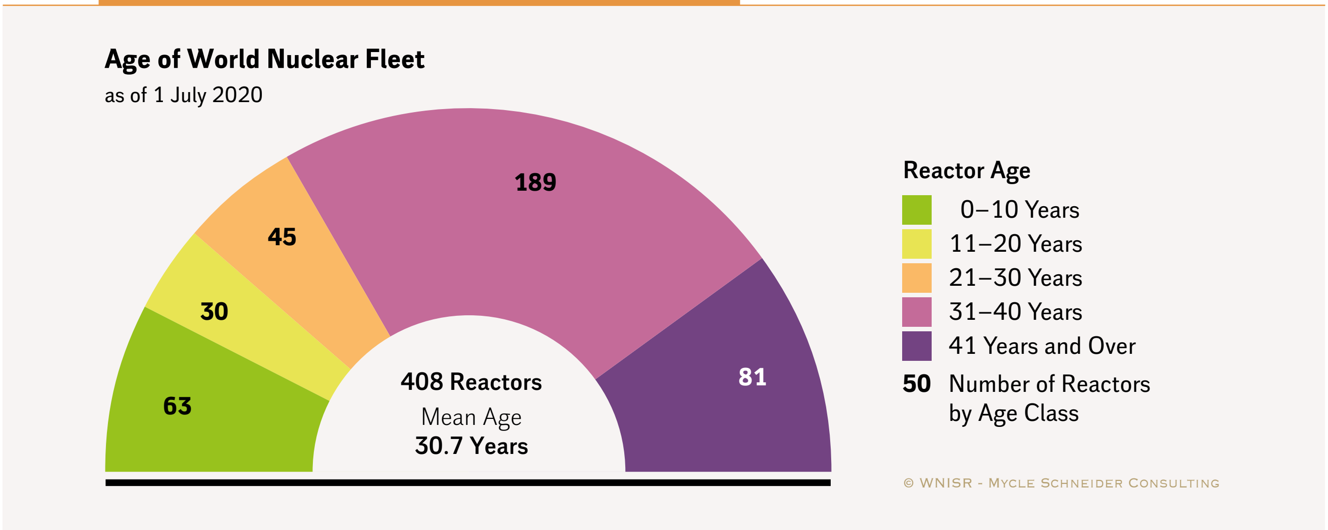
OPERATING AGE

In the absence of significant new-build *and* grid connection over many years, the average age (from grid connection) of operating nuclear power plants has been increasing steadily since 1984 when it stagnated, and as of mid-2020 it is standing at 30.7 years, up from 30.1 years in mid-2019 (see Figure 12).[63]

A total of 270 reactors, two-thirds of the world's operating fleet, have operated for 31 or more years, including 81 (~20 percent) reaching 41 years or more.

In 1990, the average age of the operating reactors in the world was 11.3 years, in 2000 it had advanced to 18.8 years and by 2010 it stood at 26.3 years. The different development stages amongst the Top-5 nuclear fleets in the world illustrates the historic shift in the nuclear power sector. The two leading nuclear nations are also leading the age pyramid. The U.S. passes the 40-year average age in 2020, and France's fleet exceeds 35 years. Russia inversed the curve starting in 2016 and its average fleet age of 28.5 years in mid-2020 remains one and a half years below the 2015-average. South Korea's reactors at just above 20 years remain half as old as the U.S. fleet, and China is the obvious newcomer with an average fleet age of just 8.2 years. (See Figure 13).

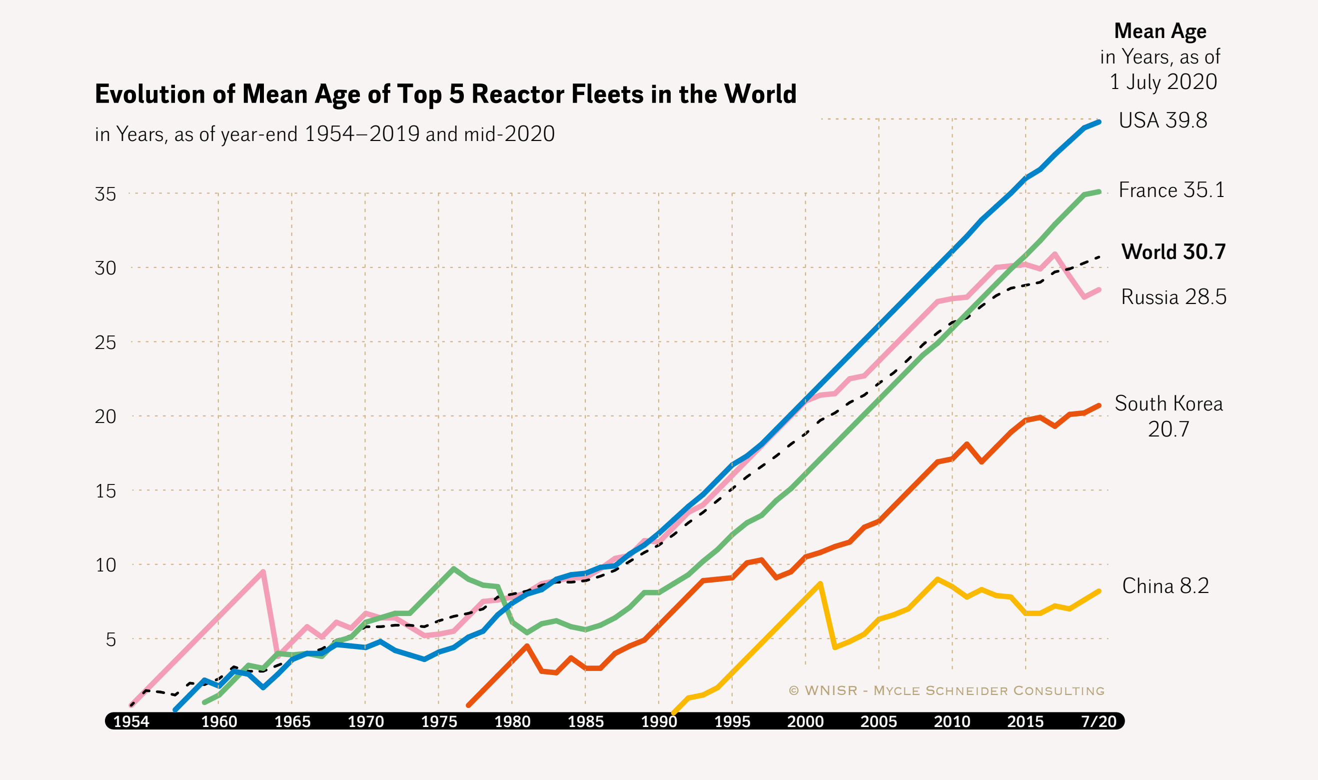
Figure 12 · Age Distribution of Operating Reactors in the World



Sources: WNISR, with IAEA-PRIS, 2020

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

Figure 13 · Reactor-Fleet Age of Top 5 Nuclear Generators



Sources: WNISR, with IAEA-PRIS, 2020

Some 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.

As of mid-2020, 97 U.S. units had received a license extension. Six units with renewed licenses were closed early, and two applications for three reactors were withdrawn as Crystal River was closed and the other two at Diablo Canyon will close when their current license expires in 2024–2025 (see United States Focus). Two additional applications for three reactors are expected in 2021–2022.[64]

Only six of the 38 units that have been closed in the U.S. had reached 40 years on the grid. All six 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 reactors connected to the grid in the U.S. never reached their initial design lifetime of 40 years. None of them reached 50 years of operation. On the other hand, of the 95 currently operating plants, 46 units have operated for 41 years or more; thus, half of the units with license renewals have already entered the lifetime extension period, and that share is growing rapidly with the mid-2020 mean age of the U.S. operational fleet at about 40 years (see United States Focus).

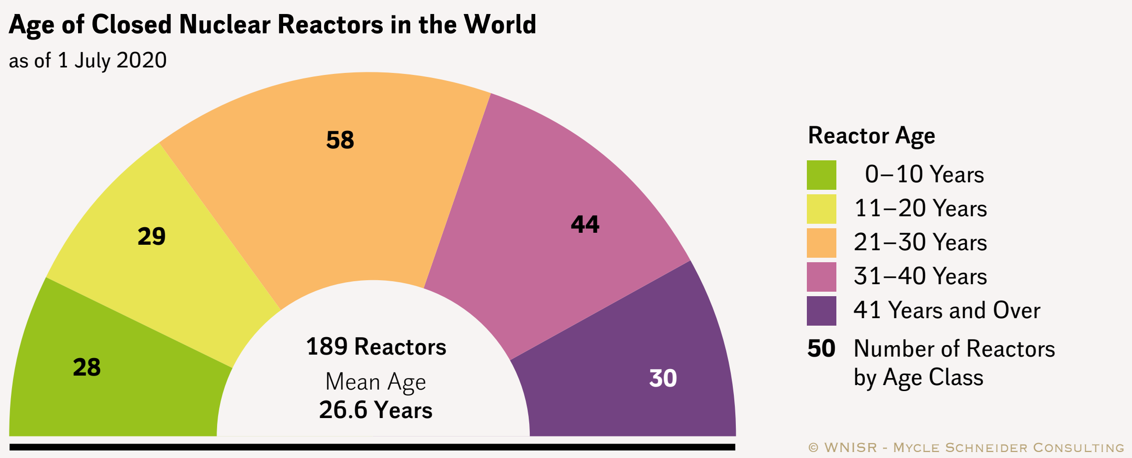
64 - U.S.NRC, “Status of License Renewal Applications and Industry Activities”, Updated 3 March 2019, see http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 23 August 2020.

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 35.1 years on average, and most of them have completed the process with the French Nuclear Safety Authority (ASN) evaluating each reactor allowing them to operate for up to 40 years, which is the limit of their initial design age. However, the ASN assessments are years behind schedule. For economic reasons, the French state-controlled utility Électricité de France (EDF) clearly prioritizes lifetime extension to 50 years over large-scale new-build.[65] EDF's approach to lifetime extension is still under review by ASN and its Technical Support Organization (TSO). ASN plans to provide its opinion on the general assessment outline by the end of 2020. The program has cumulated various delays, and it is somewhat ironical that Tricastin-1, the first unit to undergo the fourth decennial review, has done so in 2019 without the completion of ASN's generic approval of the procedure. In addition, lifetime extension beyond 40 years requires site-specific 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 a 60-year license for its 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 those that have already closed (see Figure 12 and Figure 14). The age structure of the 189 units already closed (eight more than one year ago) completes the picture. In total, 74 of these units operated for 31 years or more, and of those, 30 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 26.6 years.

Figure 14 · Age Distribution of Closed Nuclear Power Reactors

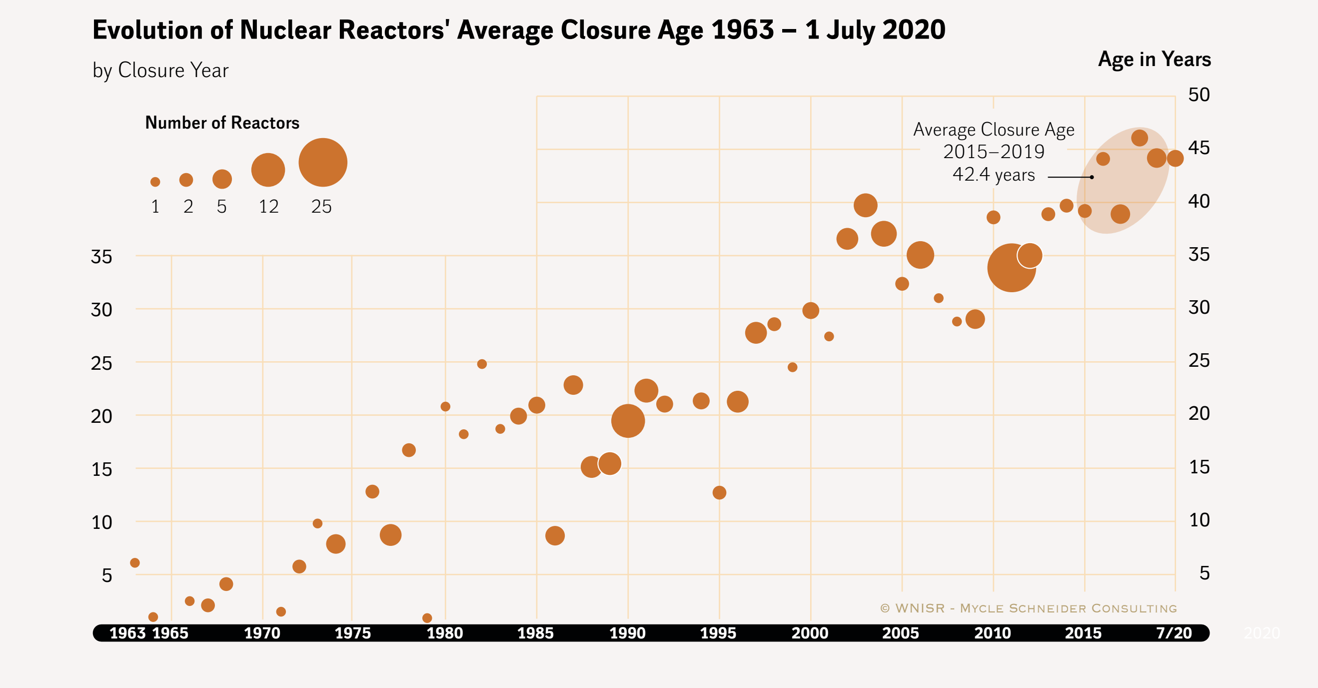


Sources: WNISR, with IAEA-PRIS, 2020

To be sure, the operating time prior to closure has clearly increased continuously. The mean age at closure of the 17 units taken off the grids between 2015 and 2019 was 42.4 years (see Figure 15).

65 - In fact, EDF does not have the choice as it does not have the financial capacity to engage into a major new-build program, as a recent report by the French Court of Accounts confirmed (see France Focus).

Figure 15 · Nuclear Reactor Closure Age 1963–1 July 2020



Sources: WNISR, with IAEA-PRIS, 2020

As a result of the Fukushima nuclear disaster (also referred to as 3/11), questions have been raised about 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 it is clear that 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.

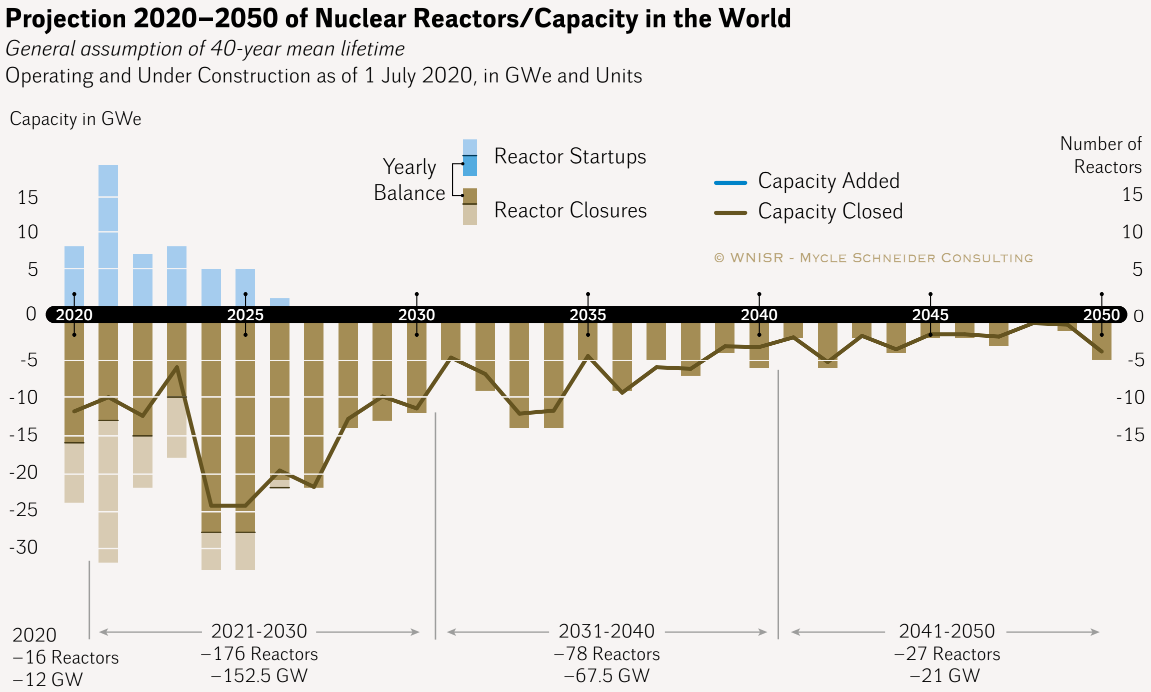
LIFETIME PROJECTIONS

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 16), assumes a general lifetime of 40 years for worldwide operating reactors—not including reactors in Long-Term Outage (LTO). The 40-year number corresponds to the design lifetimes of most operating reactors. Some countries have legislation or policy (Belgium, South Korea, Taiwan) in place 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 81 reactors that have passed the 40-year lifetime, 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 17) takes into account all already-authorized lifetime extensions.

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. With all units under construction scheduled to have started up, installed nuclear capacity would still decrease by 10.5 GW by the end of 2020. In total, 16 additional reactors (compared to the end of 2019 status) would have to be started up or restarted prior to the end of 2020 in order to maintain the status quo of operating units.

Figure 16 · The 40-Year Lifetime Projection



Sources: Various, compiled by WNISR, 2020

Notes pertaining to Figure 16, Figure 17 and Figure 18:

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 2021 and 2025, as there are no official dates.

The restart of one reactor (Darlington-2) from LTO prior to 7/2020 appears as "startup". Restart and closure of 31 reactors in LTO after 1 July 2020 are not represented here.

The figures take into account "early retirements" of five reactors in the U.S.; in the case of four additional reactors, the reversal of early retirements has been maintained although they are likely to be repealed, and others might be added (see United States Focus, Table 9); as well as political decisions to close reactors prior to 40 years (Germany, South-Korea).

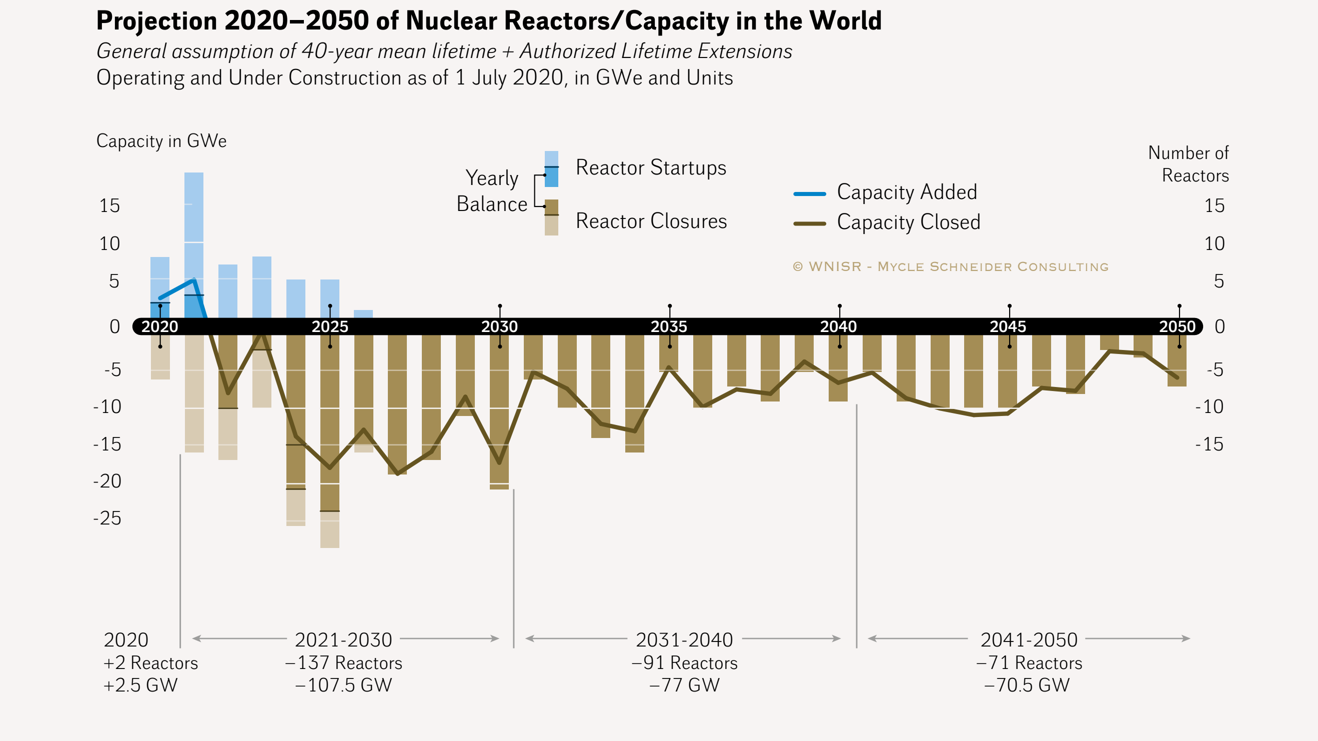
In the case of French reactors that have reached 40 years of operation prior to 2020 (start-up before 1980), we use the limit date for their 4th periodic safety review (visite décennale) as closing date in the 40-year projection. For all those that have already passed their 3rd periodic safety review, the scheduled date of their 4th periodic safety review is used in the PLEX projection, regardless of their start-up date.

In the following decade to 2030, 176 additional new reactors (152.5 GW) would have to be connected to the grid to maintain the status quo, three times the rate achieved over the past decade (58 startups between 2010 and 2019).

The stabilization of the situation by the end of 2020 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 more or less continue to stagnate at best, unless—beyond restarts—lifetime extensions become the norm 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 more or less successful 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 figures for China's 2020 target for installed nuclear capacity have fluctuated between 40 GW and 120 GW in the past. The freezes of construction initiation for almost two years and of new siting authorizations for four years have significantly reduced Chinese short-term ambitions.

Figure 17 · The PLEX Projection (not including LTOs)



Sources: Various, compiled by WNISR, 2020

Notes: Refer to notes below Figure 16.

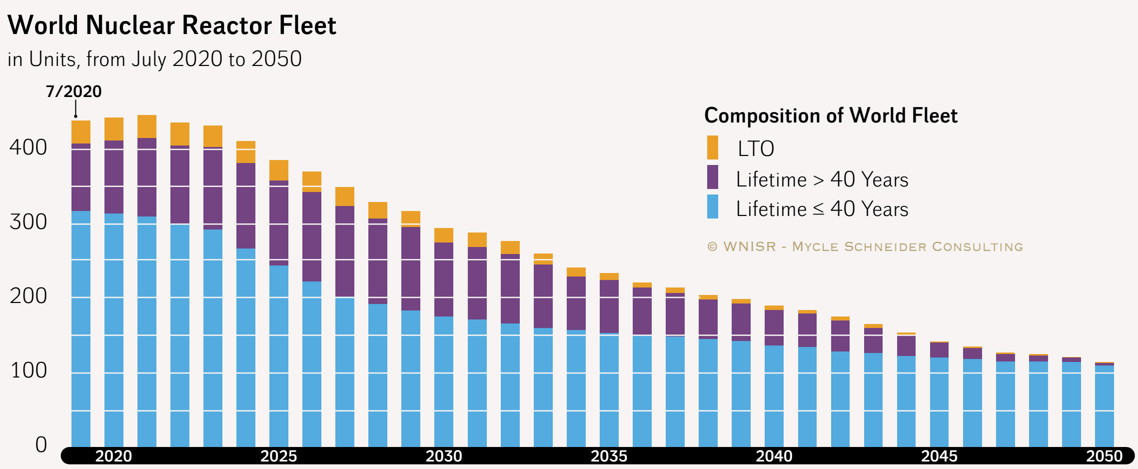
Every year, WNISR also models a scenario in which all currently licensed lifetime extensions and license renewals (mainly in the U.S.) are maintained and all construction sites are completed. For all other units, we have maintained a 40-year lifetime projection, unless a firm earlier or later closure date has been announced. By the end of 2020, the net number of operating reactors would increase by two units, and the installed capacity would grow by 2.5 GW.

In the following decade to 2030, the net balance would turn negative as soon as 2022, and an additional 137 new reactors (107.5 GW) would have to start up to replace closures.

The PLEX-Projection would still mean, in the coming decade, a need to more than double the number of units built annually over the past decade from 5.8 to 13.7 (see Figure 16, Figure 17 and the cumulated effect in Figure 18).

In the meantime, construction starts have been on a declining trend for a decade. Between 2010 and 2014, a total of 40 constructions were launched around the world, of which 18 in China and five later abandoned, thus an average of seven units per year were launched and sustained. Between 2015 and 2019, constructions started at only 27 units, of which 13 in China, thus an average of 5.4 construction starts per year, significantly less than half of the 13.7 that would be needed according to the PLEX Projection over the coming decade just in order to maintain the current number of operating reactors in the world.

Figure 18 · Forty-Year Lifetime Projection versus PLEX Projection



Sources: Various, compiled by WNISR, 2020

Notes: This figure exclusively represents the evolution over time of world reactor fleet as it is currently operational or under construction. It does not take into account any assumptions on potential further constructions or additional early closures beyond those currently decided.

For details refer to Notes below Figure 16.

NUCLEAR POWER IN THE AGE OF COVID-19

"With the COVID-19 crisis, for the first time in its history, the nuclear industry is confronted with crisis management involving safety challenges that has not a technical cause linked to its activities as origin."

Bernard Doroszczuk, President, ASN

29 April 2020

INTRODUCTION

The COVID-19 pandemic had and continues to have severe global repercussions and the nuclear industry is no exception. Remarkably little information is available on COVID-19 cases in nuclear facilities and amongst regulator staff. Virtually nothing is known about testing and its results. Nevertheless, industry representatives have not stopped claiming how well the establishment has coped with the crisis and how crucial it has been. The World Nuclear Association's Chair Agneta Rising stated late March 2020[66]:

> I would like to pay particular tribute to the utilities, their workers and their suppliers who are keeping their reactors running during this public health crisis. Their work reminds us just how crucial nuclear energy is as a source of 24/7 electricity supply.

The OECD Nuclear Energy Agency's Director General William Magwood pointed out in early April 2020[67]:

> It is the norm in the nuclear sector to change processes and practices only after deliberate analyses, with numerous viewpoints taken into account; but today's crisis calls upon all for quick responses. Decisions must be made rapidly in situations that have no complete parallel. Regulators must adjust their plans for inspections. Operators will defer outages and modifications to their plants.

In early June 2020, the European Commission issued an 8-page working paper on "Good Practices to Address Pandemic Risks"[68] stating confidently:

> Nuclear power plant regulators and operators ensured that there was no adverse impact on nuclear safety and supported continued Euratom Safeguard verifications by the European Commission, as far as safely possible.

There is no explanation what restrictions were implied by "as far as safely possible".

In fact, the consequences of COVID-19 on the nuclear industry and the regulators are substantial, and the impact will last for many months to come and well into 2021–2022. As

66 - Agneta Rising, "Message: Nuclear power in the fight against COVID-19", World Nuclear Association, as published in *WNN*, 27 March 2020, see https://world-nuclear-news.org/Articles/Message-Nuclear-power-in-the-fight-against-COVID19, accessed 28 June 2020.

67 - *WNN*, "Magwood outlines Nuclear Energy Agency's response to pandemic", 9 April 2020, see https://world-nuclear-news.org/Articles/Magwood-outlines-Nuclear-Energy-Agencys-response, accessed 1 July 2020.

68 - European Commission, "Energy Security: Good Practices to Address Pandemic Risks", Commission Staff Working Paper, 2 June 2020, see https://ec.europa.eu/energy/sites/ener/files/1_en_document_travail_service_part1_v3.pdf, accessed 19 August 2020.

detailed below, refueling and maintenance outages were postponed, testing of key components delayed, physical inspections by safety authorities halted altogether. Some fear shortages in nuclear fuel supply due to logistical disruptions. These delays could lead to situations when outages need to be carried out in times of high demand.

The consumption of electricity, however, dropped significantly in some regions during the confinement periods and is not likely to reach pre-pandemic levels for many months—if not years, given the severe global recession—which will have a major impact on the financial and economic health of nuclear utilities, which were often already facing difficulties.

Permanent, independent oversight is crucial in any high-risk activity, for technical reasons and because of the possibilities for human errors. Effective regulation and control are not only of primary importance because of the very large danger potentials involved and the overall advanced ageing of the facilities. There is also a history of criminal wrongdoing, including in the major nuclear countries. Systematic irregularities, including falsifications, of manufacturing documentation has persisted for several decades at Creusot-Forge (now Le Creusot) in France[69]; quality-control procedures have been twisted in Japan for years[70] and a new bribery scandal hit the country in the summer of 2020 (see Japan Focus); quality-guarantee certificates were faked for thousands of pieces in the South Korean industry[71]; in Brazil, a former President has been jailed because he was involved in the bribery scheme of a nuclear construction project[72]; in the U.S. state Ohio, prominent legislators were indicted for bribery related to legislation to provide subsidies for uneconomic reactors,[73] in South Carolina, the head of nuclear new build pled guilty to fraud charges related to the canceled project V.C. Summer,[74] and a Europe-wide bribery system of nuclear waste shipments involving several European countries shook up the industry in the late 1980s[75]. These are merely a few examples, some of which have been thoroughly documented in various editions of the WNISR.

Physical inspections by regulatory authorities in nuclear facilities are therefore necessary. Halting them altogether for many weeks is not without consequences.

69 - ASN, "ASN reviews the steps taken to deal with counterfeit, suspect and fraudulent items (CSFI)", Information notice, 8 June 2018, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-reviews-the-steps-taken-to-deal-with-counterfeit-suspect-and-fraudulent-items-CSFI; and ASN, "AREVA has informed ASN of irregularities concerning components manufactured in its Creusot Force plant", Information notice, 4 May 2016, see http://www.french-nuclear-safety.fr/Information/News-releases/Irregularities-concerning-components-manufactured-in-its-Creusot-Forge-plant; both accessed 28 August 2020.

70 - Elaine Kurtenbach and Mari Yamaguchi, "Kobe Steel Announces More Cases Of Faked Inspections Data", *Associated Press*, as published by *Manufacturing Business Technology*, 13 October 2017, see https://www.mbtmag.com/quality-control/news/13227522/kobe-steel-announces-more-cases-of-faked-inspections-data, accessed 28 August 2020.

71 - Max S. Kim, "How greed and corruption blew up South Korea's nuclear industry", *MIT Technology Review*, 22 April 2019, see https://www.technologyreview.com/2019/04/22/136020/how-greed-and-corruption-blew-up-south-koreas-nuclear-industry/, accessed 26 August 2020.

72 - Brad Brooks and Anthony Boadle, "Brazil's ex-President Temer jailed, accused of heading 'criminal organization'", *Reuters*, 21 March 2019, see https://www.reuters.com/article/us-brazil-corruption/brazils-ex-president-temer-arrested-threatening-fiscal-reform-idUSKCN1R21JW, accessed 26 August 2020.

73 - Giulia McDonnell Nieto del Rio, "Powerful Ohio Republican Is Arrested in $60 Million Corruption Scheme", *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; and Gregory Meyer, "Ohio corruption case throws focus on US nuclear plant troubles", *Financial Times*, 22 July 2020, see https://www.ft.com/content/451324c6-9f9d-48a1-b2d9-76d731e99db6; both accessed 26 August 2020.

74 - Andrew Brown and Avery G. Wilks, "Former SCANA executive pleads guilty to fraud charges tied to failed SC nuclear project", *Post and Courier*, 23 July 2020, see https://www.postandcourier.com/business/former-scana-executive-pleads-guilty-to-fraud-charges-tied-to-failed-sc-nuclear-project/article_26e23ca8-c50b-11ea-8377-e7b39854212b.html, both accessed 25 July 2020.

75 - Mycle Schneider, "Transnuklearaffäre—Über die Arbeit des Untersuchungsausschusses im EP", November 1988.

OVERVIEW OF KEY SAFETY AND SECURITY ISSUES

The following analysis focuses on nuclear power plants. However, this does not mean that the potential impact of a pandemic on other nuclear facilities can be neglected. In fact, the operation of most of the nuclear fuel chain facilities considered non-essential for continued short-term operation of nuclear power plants was halted in many nuclear countries, including spent fuel reprocessing plants in France and in the U.K.

The operational status of a plant is crucial for any risk assessment. There is a clear difference of the risk level between operating power plants and plants in cold shutdown status.

Some of the following areas of concern are also applicable to other nuclear facilities, e.g. reprocessing plants or larger research reactors:

- **Periodic testing with short time-intervals** like several weeks. This type of testing is done at systems to provide assurance that vitally important functions like the emergency control room operations, emergency electricity supply, emergency core cooling or (at PWRs) emergency feedwater supply are in good working order. The test intervals had been determined by failure probabilities derived from operating experience. Because of their risk importance, these test intervals are generally fixed by guidelines and/or plant specific provisions; to follow these is a legal obligation of the operator. To prolong the test intervals means a risk increase of unidentified failures of those systems and an increase of failure probability in emergency situations, i.e. situations, where the systems are necessary to prevent catastrophic accidents or to mitigate their consequences. If operators prolong the test intervals without appropriate review and analysis either by the operator or regulator, they violate their safety obligations. There can be—and in fact has been (see examples hereunder)—a formal acceptance by the relevant regulatory authority of prolonged test intervals because of an exceptional situation, like a pandemic. But in some of those cases the authority violates the general principle of "nuclear safety first".
- **Periodic inspections at low frequency** like once in several years. These include detailed inspections of many electrical and mechanical components in key areas of the plant. It includes also ultrasonic testing of large components like reactor pressure vessels, primary circuit components or steam generators at PWRs; the purpose is to follow the growth of cracks or other weaknesses like wall-thinning up to potentially hazardous dimensions. The information gained is necessary to decide whether a repair or a replacement of the component must be implemented. Those tests and inspection walks are necessarily performed during planned outages for maintenance and refueling as the components have to be accessible in terms of temperatures, absence of high pressures and excessive levels of radiation.
- These outages typically involve significantly increased numbers of workers needed for the preparation and implementation of the tests. The inspection intervals have also been determined by failure probabilities derived from operational experience. To prolong the inspection intervals, for example by the decision to delay outages to avoid large numbers of additional workers on-site, means a clearly increased loss of control over weaknesses of mechanical or electrical components.
- Normally periodic testing and inspections—both low-frequency and high-frequency—are performed under **the four-eyes principle** (**at least two people have to be always present**). This implies close contact between the persons involved. If the rules are

weakened due to social distancing needs caused by the pandemic, the probability of mistakes grows, which means a higher risk of potential system failures.

- In some countries, the relevant safety authorities and their Technical Support Organizations (TSOs) have decided to **halt site visits or to dramatically reduce their frequency**. The U.S. NRC implemented a reduced inspection program, e.g. In countries where the authorities rely on experts from TSOs or from third party inspectors, the analogue reduction of inspections by these experts was or is being considered. Some regulators have shifted to just inspecting the paperwork (e.g. in France). However, there is a significant difference between judging safety only on the basis of paperwork examinations and the physical inspections of facilities; unreported situations might become visible only in the presence of an inspector. Although the operator is entirely responsible for the quality of testing and maintenance, experience has shown that additional inspections by regulators or other entities enhance the quality of the results, as more failures or weaknesses are detected. The reason is clear: different people, especially when they come from different organizations, have different inspection methods and identify issues of non-compliance with standards and regulations. Experience also shows that during a physical inspection sometimes irregularities are detected, which have not been the original focus of a given specific inspection. A well-known example is the inspection in the US-plant Davis Besse, where a strong degradation of the reactor pressure vessel lid was detected by chance. Limiting inspections to paperwork instead of the real plant can hide a lot of safety weaknesses. Again, restrictions or reductions in inspection intensity and quality lead to an increasing probability of major failures.

- Special problems arise with the **control room staff**, people with very specific knowledge and training and with a specific formal qualification. In most countries, a very limited number of people have acquired this qualification. A pandemic needs reduction of social contacts not just at work but in day-to-day life:

  - The full staff of the control room has to be present in a limited space.
  - It is necessary to perform actions under the four-eyes principle, which is impossible without at least two people being in proximity.
  - Each outgoing shift has to inform the incoming shift on all important developments of the previous hour.

- If there is an infection or the need for quarantine amongst the limited number of qualified control-room staff, this can reduce available operators below the necessary minimum. This seems to be of particular concern for countries with only one (Armenia, Iran, Netherlands, Slovenia) or a small number (<5) of operating reactors (e.g. 3 in Argentina, 2 each in Brazil and Bulgaria, 4 each in Finland, Hungary, Slovakia, Switzerland, Taiwan). However, in most countries shift staff in the control room are not licensed for all or even several reactors in a given country, as they have obtained a license only for a specific plant or for a group of identical reactors. The reason is that the control features and systems often have big differences between individual plants; that is specifically the case for those needed in an emergency. In case of an emergency event, the control room staff must be aware of these very specific features to avoid failures. Therefore, in most cases, it is not possible to replace staff impacted by a pandemic by staff from other plants, as those usually have no additional license and training for various plants (with the exception of staff from identical "sister-plants"). This means, even countries with a large reactor fleet are faced with the same problem. The situation in France, Russia and Ukraine with a significant number of identical (or almost identical) plants is not typical for any other country with a large reactor fleet. And even in the case of these three exceptions, a staff exchange would only be possible within a group of one specific design, not for all reactors in the country. For example, the U.S. and Japan have many different designs of control room and emergency systems, even if the nuclear steam supply system can be of a similar type. Even smaller fleets are often surprisingly diverse, e.g. Germany's remaining six reactors have four different designs, and Switzerland's four operating units are of three different designs.

Quarantining entire shifts—as was done in some cases—is not without risk either. The IAEA stresses: "It is also important to note that there is potential for common cause failure, as operators reside together in communities."[76]

In terms of nuclear risk management, the cessation of reactor operation is unavoidable once critical limits are reached and switch to shutdown mode, which requires less staff in the control room. What to do, if even minimum staffing for the shutdown mode is not guaranteed, remains an open question. Fortunately, no such case has been reported yet.

- Regarding possible **nuclear emergency situations** in times of a pandemic, it is clear that rules of social distancing and imperatives of addressing the situation contradict each other. This is especially the case, when a nuclear event needs quick response or densely staffed spaces, like the emergency control room or emergency staff rooms. The emergency control room is a second control room in the nuclear power plant, from where it is possible to activate and stop a number of the essential safety systems of the plant. It is implemented for situations when the main control room becomes inaccessible, for example, because of a fire or toxic gas buildup. In general, emergency control rooms are not very large and so incompatible with social distancing. The emergency staff room is separate from the main control room, but onsite. In case of an emergency, a group of additional specialists and decisionmakers (emergency staff) that is collecting information on the situation for evaluation and decision making will be using this room. It is designed for many people to stand or sit side-by-side in a very limited space. The existing rules of procedure for both emergency control rooms and emergency staff rooms do not reflect a situation where social distancing is necessary. Therefore, in the future it would be crucial to have appropriate rules of procedure in advance to deal with such conflicting issues in case of a nuclear accident during a pandemic.
- **Offsite emergency response** plans rely heavily on evacuating local population groups to designated centers. These centers densely pack people into areas in which COVID-19 social distancing rules would be violated. Moreover, large numbers of public safety officials must coordinate the offsite response. Current plans, in the U.S., e.g., require large numbers of officials to meet and direct the response from centralized emergency response rooms with limited ability to maintain social distancing.
- Nuclear plants are **highly sensitive for terroristic attacks** because of the potential consequences that could result from such an attack. Regarding plausible terroristic attack scenarios, one has to differentiate between external attacks and attacks from inside. The main impact of a pandemic on scenarios of external physical attacks is related to potential reductions in available security forces. These are highly trained teams with particular knowledge of the facilities they have to guard. Similar to control-room staff, there are

76 - IAEA Board of Governors, "The operation, safety and security of nuclear and radiation facilities and activities during the COVID-19 Pandemic", Report by the Director General, GOV/INF/2020/8, 4 June 2020, see https://www.iaea.org/sites/default/files/20/06/govinf2020-8.pdf, accessed 19 August 2020.

only a limited number of specialized security personnel and contamination amongst these forces could lead to a serious security deficit on-site. In some countries, e.g. the U.S., certain security trainings have been suspended during the COVID-19 pandemic.77

Attacks are also possible from the inside, be it mechanical or electronical. Scenarios for those attacks include cases with step by step preparation of degradation of safety relevant systems; with the objective that they do not protect adequately, when the attack itself starts. In "normal" times, there is a certain probability that tests and walkdowns for inspection (or even for other purposes) in the respective areas detect such manipulations. If the tests are reduced in number and if walkdowns were strongly reduced, then a potential terrorist has a better chance to prepare an attack and go undetected.

RESPONSE STRATEGIES TO COVID-19 BY OPERATORS AND REGULATORS AROUND THE WORLD

Several international organizations have issued assessments of the impact and recommendations for nuclear establishments how to cope with the COVID-19 pandemic. The following section provides an overview of reactions by the IAEA, the OECD-NEA and other international and national organizations.

On 4 June 2020, the IAEA's Director General reported to the Board of Governors on the "operation, safety and security of nuclear and radiation facilities and activities" during the COVID-19 pandemic.[78]

The 10-page paper stated:

> The impact of the COVID-19 pandemic has been far reaching. (...)
>
> National policy decisions made by governments have direct and indirect repercussions to organizations in the nuclear and radiological field, for example in the area of human resources. Decisions in one country could have affected facilities in other countries, for example through introducing supply chain difficulties in large scale projects such as outage management, major refurbishment or new plant construction. (...) The stretching of government infrastructure capacity could also potentially have an impact on the emergency preparedness of nuclear and radiation facilities.

The IAEA's DG also pointed out that the crisis is without precedent: "COVID-19 is the first pandemic of this scale in the history of the nuclear industry." The Agency saw its role as a facilitator of information exchanges between Members States and operators. It set up an international peer-to-peer network (COVID-19 OPEX Network) on nuclear plant operation. The pandemic's impact on training activities and human resources policies is to be discussed at a special meeting in October 2020. A number of meetings have been cancelled and rescheduled, including the Eighth Review Meeting of the Convention on Nuclear Safety (CNS) and the 7th

77 - Christopher G. Miller, "Updated Implementation of resident inspector site coverage during COVID-19", Division of Reactor Oversight, Office of Nuclear Reactor Regulation, U.S.NRC, Memorandum dated 6 April 2020, see https://www.nrc.gov/docs/ML2009/ML20097E538.pdf, accessed 8 September 2020.

78 - IAEA, "The operation, safety and security of nuclear and radiation facilities and activities during the COVID-19 Pandemic", Report by the Director General, 4 June 2020, op. cit.

Review Cycle of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (The Joint Convention).

While the IAEA noted multiple disruptions of ordinary schedules and procedures, [79] it remarkably states: "No Member State reported the enforced shutdown of any nuclear power reactors resulting from the effects of COVID-19 on their workforce or essential services such as supply chains." In fact, according to the IAEA, in Brazil, Finland, Iran, the Netherlands and Switzerland, "generation is expected to exceed original 2020 estimates because outages were either shortened or deferred to 2021".[80]

In the EU, the European Commission recognizes that the energy sector "faces unique constraints as regards the continuity of critical operations, safety and the immediate cascading effects across sectors and Member States in case of incidents."[81] The Commission also stated:

> It is worth noting that the steep reduction in electricity demand during the COVID-19 pandemic has led to a higher share of renewables in the electricity mix, while the electricity system and balancing continued operating normally.

The Commission issued guidelines to allow for the free movement of workers to make sure that refueling of nuclear plants as well as other key activities in the energy sector (e.g. maintenance of offshore wind farms) was not impacted. One of 20 "good practices" during the pandemic stipulates a "pragmatic risk-based approach by national regulators, in particular the nuclear sector".[82] Indeed, nuclear safety authorities seem to be handling the crisis in a very flexible and pragmatic manner, as illustrated in the overview below.

GENERAL DIFFICULTIES AND MEASURES

A range of measures to cope with the COVID-19 pandemic were taken by operators and regulators in most countries operating or building nuclear facilities, in many cases consisting in the reduction or elimination of activities judged non-essential, implementation of social-distancing rules and the rescheduling of refueling and maintenance outages. The IAEA received reports of outage impacts at nuclear plants in 26 of the 30 Member States with operating reactors:[83]

> In some cases, outage scopes were reduced by eliminating non-critical work to minimise external staff brought on-site. In other cases, outages were extended to allow work to proceed at a slow pace that accommodated physical distancing constraints. In still other cases entire outages were deferred to next year. The full impact will play out over at least the next year as future outage plans are revised to complete deferred work.[84]

79 - A range of issues encountered are important but beyond the scope of the WNISR, e.g. the IAEA DG stated: „There has been significant disruption in the distribution of medical isotopes and radioisotopes."

80 - IAEA, "The operation, safety and security of nuclear and radiation facilities and activities during the COVID-19 Pandemic", 2020, op. cit.

81 - European Commission, "Energy Security: Good Practices to Address Pandemic Risks", Commission Staff Working Paper, June 2020, op. cit.

82 - Ibidem.

83 - The 31st country with operating units is Taiwan, which is not an IAEA Member State.

84 - IAEA, "The operation, safety and security of nuclear and radiation facilities and activities during the COVID-19 Pandemic", 2020, op. cit.

Other measures included regular medical screenings, travel restrictions, self-isolation and physical meeting restrictions. Mitigation plans at some facilities resulted in a need for more licensed personnel, which is being "satisfied by newly trained as well as previously qualified staff, including recent retirees and instructors", reports the IAEA. "However, this approach in itself is facing challenges in maintaining the required quality and quantity of training in the context of other restrictions limiting the ability to assemble employees."

Nuclear regulators have taken similar steps as the operators to mitigate the effects of the pandemic. These include virtual rather than face-to-face meetings internally and with regulators in other countries, moving from physical inspections to remote monitoring, and issuing exemptions to regulations. Trade journal *Nuclear Intelligence Weekly* (*NIW*) reported:

> These exemptions—allowing significantly longer work weeks for plant employees and deferring maintenance and inspection, in some cases for up to two years—are precisely why regulators are encountering criticism. Beyond that, workers at some plants have complained either publicly, or via media leaks, that operators aren't doing enough at plant and/or newbuild sites to prevent the spread of COVID-19. And health officials in some communities have requested that refuelings be postponed.[85]

NIW also published a compelling analysis on the impact of the COVID-19 crisis on the nuclear fuel manufacturing industry and the risks to nuclear power plant operators and concluded that

> …for nuclear operators dependent on one single fuel fabricator, the risks are acute: a severe localized COVID-19 outbreak could threaten the supply of fuel assemblies for whole fleets of reactors in India, Russia, South Korea or the UK. Even for operators with more diversified suppliers in Europe and the US there could be problems.[86]

The state-by-state response to the COVID-19 crisis and a "dearth of leadership from the top" make the U.S. supply chain "more vulnerable", according to *NIW*:

> Risks to factories are twofold: First, in areas under stay-home orders, their workers might not be declared essential and therefore be forced to quarantine at home, and second—particularly in regions where governments are more lax about quarantining—that a localized outbreak sickens too many employees for the facility to operate safely.[87]

Reportedly, only Framatome and Westinghouse have requested exemptions to regulatory obligations. According to an NRC spokesperson, "Westinghouse has requested to defer until 2021 an internal emergency planning audit because a Westinghouse corporate team cannot currently go to the site" and a Framatome representative indicated that "although the company has reduced on-site staff at its Richmond plant by almost half, the company has all the components it needs in stock to meet spring and fall refueling outages".[88]

The pandemic also impacted the construction of new plants in at least 12 of the current 17 countries building nuclear reactors but apparently nowhere were construction activities halted altogether (see also Middle East Focus).

85 - Jessica Sondgeroth and Gary Peach, "Safety: Nuclear Overseers Vary Response to Covid-19", *NIW*, 5 June 2020, see http://www.energyintel.com/pages/eig_article.aspx?DocId=1074603&NLID=104, accessed 19 August 2020.

86 - Jessica Sondgeroth and Phil Chaffee, "Fabricators Prepare for Potential Supply Disruptions", *NIW*, 17 April 2020.

87 - Ibidem.

88 - Ibidem.

COUNTRY-BY-COUNTRY OVERVIEW

The following section provides a country-by-country overview of reported COVID-19 cases at nuclear facilities as well as countermeasures taken by operators and regulators.[89] *In fact, very few operators and regulators have published and regularly updated data about detected COVID-19 cases and their handling. The Swiss NGO Physicians for the Environment* (Ärztinnen und Ärzte für Umweltschutz) *has openly criticized the refusal by the national regulator to respond to any questions about testing and positive cases in nuclear facilities in the country.*[90]

Argentina

Measures and Impacts

Staff at the three operating reactors in the country work in staggered 14-day shifts, with 14 days off in between. Thermal imaging cameras at the entrances check for body temperatures exceeding 37°C for anyone entering the plant. The nuclear power plant operators have been seeking regulatory approval to reschedule all planned outages.[91]

Construction work on the **Carem-25** was entirely stopped in March 2020 and had not restarted in early July 2020. Work on the **Atucha-1** dry storage project has been given permission to continue during the quarantine as the site is running out of storage space in the spent fuel pool.

Armenia

Measures and Impacts

The shutdown dates for preventive maintenance at Metsamor, the single operating reactor in the country, were postponed for 45 days to 1 July 2020. Reportedly, "borders closures have complicated the conclusion of agreements on the supply of necessary equipment and materials".[92]

Belarus

Infections

As of late May 2020, the Ostrovets construction site counted around 100 confirmed COVID-19 cases amongst the workforce of about 4,000.

89 - Unless otherwise indicated, the information in this section is based partially on IAEA, "The operation, safety and security of nuclear and radiation facilities and activities during the COVID-19 Pandemic", June 2020, op.cit., and on INRAG, "Nuclear Safety and Security During a Pandemic", Working Paper, 24 April 2020, see https://www.inrag.org/nuclear-safety-and-security-during-a-pandemic-2, accessed 16 July 2020.

90 - AefU, "Die Sicherheit der Atomkraftwerke darf keine Geheimsache sein!", Ärztinnen und Ärzte für Umweltschutz/Médecins en faveur de l'Environnement, Press Release, 23 March 2020 (in German), see http://www.aefu.ch/fileadmin/user_upload/aefu-data/b_documents/Aktuell/20190506_AefU_MM_Corona_u_AKW_Sicherheit.pdf, accessed 18 July 2020.

91 - Phil Chaffee, "Nuclearelectrica Back in The Driver's Seat", *NIW*, 10 July 2020, see http://www.energyintel.com/pages/eig_article.aspx?DocId=1077846, accessed 19 August 2020.

92 - *NEI*, "Armenian nuclear plant delays scheduled outage", 28 May 2020, see https://www.neimagazine.com/news/newsarmenian-nuclear-plant-delays-scheduled-outage-7936742, accessed 19 August 2020.

Measures and Impacts

"All the quarantine measures are being observed, but I would particularly like to ask ASE's [Atomstroyexport's] leadership and managers of the project to fortify measures even more," Rosatom Director Aleksei Likhachev said on 26 May 2020. However, *NIW* noted that "it is difficult to gauge the extent of the virus' spread given contradictory reports over the past two months and questions raised about the quality of testing in Belarus, one of a handful of countries whose leadership has expressed skepticism about the gravity of COVID-19."[93]

While the first fuel load had arrived on-site in May 2020, fuel loading of Ostrovets-1, was delayed and only started on 7 August 2020, which will likely lead to further postponing of the plant's commissioning.[94] It also remains to be seen what effect the recent strikes and opposition movements will have on the project.

Belgium

Figure 19 · "All Necessary Measures"? — No masks.

Source: Electrabel, screenshot, 8 August 2020.[95]

Note: The title of the picture says "Coronavirus: the Belgian nuclear power plants take the necessary measures". The photo shows three Electrabel employees without masks and no social distancing. The page has not been updated since 15 May 2020.

Measures and Impacts

Nuclear operator Electrabel delayed refueling outages over the next three years.

Basic measures include:

- The limitation of staff on the nuclear sites;
- Remote work to the extent possible;

93 - Gary Peach, "Belarus Prepares Reactor Launch Despite Covid-19 Surge", *NIW*, 29 May 2020, see http://www.energyintel.com/pages/eig_article.aspx?DocId=1073935&NLID=104, accessed 19 August 2020.

94 - *Reuters*, "Belarus begins fuel loading at Astravets nuclear power plant -Rosatom", 7 August 2020, see https://www.reuters.com/article/belarus-power/belarus-begins-fuel-loading-at-astravets-nuclear-power-plant-rosatom-idUSL8N2F92KJ, accessed 24 August 2020.

95 - Electrabel, "Coronavirus: les centrales nucléaires belges prennent les mesures nécessaires", Engie, Undated (in French), see https://nuclear.engie-electrabel.be/fr/news/coronavirus-les-centrales-nucleaires-belges-prennent-les-mesures-necessaires, accessed 8 August 2020.

- Respect of social distancing rules;
- Wearing a mask “at strategic locations”;
- Delaying of all “non-urgent” training, meeting and maintenance activities.

It is unclear how to interpret the term “strategic location”. The photo hereunder shows three Electrabel employees without mask, and without social distancing (see Figure 19).

Measures by the Regulator

In mid-March 2020, the Belgian regulator Agence Fédérale de Contrôle Nucléaire (AFCN) halted all pro-active and scheduled inspections and its Technical Support Organization (TSO) delayed all topical inspections and reduced periodical inspections. Training certificates for nuclear transport drivers and security advisers were extended up to nine months.[96]

Other

In mid-April 2020, in the EU country the worst hit by the COVID-19 pandemic, nuclear operator Electrabel and its owner Engie requested a Government decision on the potential lifetime extension of two of the country’s seven reactors “by the end of the year”. The move did not go down well with Prime Minister Sophie Wilmès: “Bad timing, and if they don’t understand English, I will tell them that it is really not the moment to speak about that”.[97]

Brazil

Measures and Impacts

Preparatory work in order to restart construction at **Angra-3** has slowed but not stopped as a result of the COVID-19 pandemic, which is likely to further impact upon the completion schedule.[98]

Canada

Infections

No precise information is available. Industry representatives claimed that they were well prepared and have had “no known cases of COVID transmission”.[99] However, it was reported that at least one worker tested positive at the Pickering plant in late March 2020.[100]

96 - AFCN/FANC, “Organisation adaptée à partir du 14/03/2020”, Updated 15 June 2020 (in French), see https://afcn.be/fr/professionnels, accessed 20 July 2020; and AFCN/FANC, “Transport de matières radioactives”, Updated 30 April 2020, see https://afcn.be/fr/professionnels/transport-de-matieres-radioactives, accessed 19 August 2020.

97 - *Belga*, “Electrabel met la pression sur Sophie Wilmès pour prolonger le nucléaire”, as published by *RTBF*, 16 April 2020 (in French), see https://www.rtbf.be/info/economie/detail_electrabel-met-la-pression-sur-sophie-wilmes-pour-prolonger-le-nucleaire?id=10483138, accessed 18 July 2020.

98 - *BNamericas*, “COVID-19: What next for Brazil’s Angra 3 nuclear plant?”, 15 June 2020, see https://www.bnamericas.com/en/news/covid-19-what-next-for-brazils-angra-3-nuclear-plant, accessed 15 June 2020.

99 - CNSC, “Nuclear power plants: Safe adaptation during COVID-19 (Part 1)”, Commission meeting held 17 June 2020, published 10 July 2020, see https://www.youtube.com/watch?v=HPNf-wzTI2c&feature=youtu.be, accessed 28 July 2020.

100 - Maryam Shah, “Employee at Pickering nuclear station tests positive for COVID-19: OPG”, Global News, 29 March 2020, see https://globalnews.ca/news/6749184/pickering-nuclear-station-employee-covid-19-opg/, accessed 6 August 2020.

Measures

The Canadian Nuclear Safety Commission (CNSC) requires nuclear operators "to develop and implement a business continuity plan to ensure their facilities continue to operate safely at all times, including during a pandemic. Business continuity plans address how to deal with possible labour disruptions while maintaining key staffing positions."[101]

The CNSC claimed:

> We're maintaining regulatory oversight of the measures licensees are taking to help fight the spread of the virus, including staffing changes and modifications to non-essential work.

At the same time:

> We're being flexible with licensees, understanding that they will need more time to report to the CNSC on issues that are not safety significant.[102]

Planned upgrade work on the Ontario Power Generation (OPG) **Darlington** Nuclear Generating Station's Unit 3 has been postponed. Work to enhance the safety of the plant in the context of the station's plant life extension has been rescheduled for fall 2020 instead of spring 2020.[103]

OPG has scaled back the number of staff at the local generating stations but has not planned to shut down any of its reactors; indeed, its CEO has argued for continued operations of nuclear plants.[104] Further, Unit 2 of Darlington nuclear power plant, off-grid since October 2016, completed refurbishment in the middle of the pandemic, reached first criticality in April 2020 and was reconnected to the grid in June.[105]

Measures at the Regulator

Effective 16 March 2020, "CNSC staff have been directed to stay home, while critical staff continue to work to ensure effective regulatory oversight." All physical site inspections ceased entirely; commission meetings and public hearings have been postponed. On 5 May 2020, limited on-site inspections resumed. A 16–17 June 2020 meeting scheduled was held virtually and was accessible via webcast for the public.

101 - CNSC, "CNSC's response to COVID-19", 13 March 2020, Updated 10 July 2020, see https://nuclearsafety.gc.ca/eng/resources/emergency-management-and-safety/pandemic-preparedness.cfm, accessed 28 July 2020.

102 - Ibidem, April 2020.

103 - OPG, "OPG targets fall date for Unit 3 refurbishment in response to COVID-19", Ontario Power Generation, 2 April 2020, see https://www.opg.com/news/opg-targets-fall-date-for-unit-3-refurbishment-due-to-covid-19/, accessed 12 July 2020.

104 - Jennifer O'Meara, "Lights on, masks up: OPG Darlington and Pickering step up during coronavirus", *DurhamRegion.com*, 28 March 2020, see https://www.durhamregion.com/news-story/9917304-lights-on-masks-up-opg-darlington-and-pickering-step-up-during-coronavirus/, accessed 28 July 2020.

105 - 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.

China

Very little is known about the COVID-19 crisis management at nuclear facilities in China and authorities have stated that it will not impact nuclear reactor construction.[106] However, *there are* estimates that in January and February 2020, nuclear energy's contribution to the grid declined by 2.2 percent due to the pandemic.[107]

Finland

Measures and Impacts

The Finnish Radiation and Nuclear Safety Authority (STUK) believes that nuclear power plants have prepared adequately for the risks and can be operated safely. STUK, however, announced that on-site inspections will "only be carried out at sites which are the most significant for safety, and the health authorities' guidelines on avoiding close contact will be taken into account in the inspection arrangements".[108] STUK did not provide any definition of sites "most significant for safety" and no details of the measures taken by the operators and the regulator itself.

At Olkiluoto-3 (OL3), currently under construction, first fuel loading was planned for June 2020. This schedule has been postponed. As a consequence of further delays of the OL3 commissioning, due to technical reasons and the COVID-19 pandemic, the credit-rating agency Fitch revised owner TVO's outlook to negative.[109] At the same time, weaker electricity prices, partially due to the COVID-19 pandemic, impact TVO. The Average Nord Pool system price in the first quarter 2020 was €15.4/MWh (US$16.9/MWh) compared with €46.8/MWh (US$52.5/MWh) for the same period in 2019.

France

Infections

There is no systematic sector-wide information available.[110] At the Belleville nuclear power plant site, 29 COVID-19 cases had been confirmed as of the end of July 2020.[111] Worker representatives claim there are many more cases. On 20 March 2020, *Reuters* reported that EDF had "declined to comment about the level of absenteeism or the number of confirmed coronavirus infections among its staff" but had said that "its nuclear plants could operate for

106 - Muyu Xu and David Stanway, "China says virus outbreak will not impact nuclear power plant construction", *Reuters*, 15 April 2020, see https://www.zawya.com/mena/en/business/story/China_says_virus_outbreak_will_not_impact_nuclear_power_plant_construction-TR20200415nL3N2C311BX1/, accessed 27 May 2020.

107 - Xizhou Zhou, "Renewables Emerge as Winner During China's COVID-19 Lockdown", *IHS Markit*, 26 March 2020, see https://ihsmarkit.com/research-analysis/renewables-emerge-as-winner-during-chinas-covid19-lockdown.html, accessed 27 April 2020.

108 - STUK, "The Radiation and Nuclear Safety Authority (STUK) ensures its operations", 20 March 2020, see http://www.stuk.fi/web/en/-/the-radiation-and-nuclear-safety-authority-stuk-ensures-its-operations, accessed 28 July 2020.

109 - TVO, "TVO - Fitch Ratings confirmed TVO's long term credit rating at its current level BBB- and changed the Outlook to Negative", 20 April 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/fitchratingsconfirmedtvoslongtermcreditratingatitscurrentlevelbbbandchangedtheoutlooktonegative.html, accessed 28 July 2020.

110 - EDF and Orano have not replied to our questions. ASN and IRSN have communicated partial responses.

111 - Gilles Reynaud, President of Ma Zône Controlée, personal communication, 30 July 2020.

three months with a 25% reduction in staffing levels and for two to three weeks with 40% fewer staff."[112]

Mid-June 2020, **EDF** finally presented an overview of the numbers of infected staff, stating that, at the peak of the epidemic, the share did not exceed 2 percent. A total of almost 600 infections were identified over a 12-week period.[113]

On 29 April 2020, the Institute for Radiation Protection and Nuclear Safety (IRSN), which serves as the regulator's Technical Support Organization (TSO), reported 59 active COVID-19 cases, all in the course of recovering.[114] On 6 August 2020, regulator ASN reported that none of its staff had tested positive so far.[115]

Measures and Impacts

The pandemic has had major impacts on France's nuclear workforce. It was reported that of 22,500 employees of EDF's Nuclear Generation Division 15,000 were put on telework.[116]

In late March 2020, after more than a dozen EDF workers walked off at least three reactor sites over COVID-19 concerns, France's Nuclear Safety Authority (ASN) asked EDF to "ensure that health and safety conditions are communicated and set up correctly on the sites for all employees."[117]

According to ASN, various precautionary measures have been taken to deal with the COVID-19 crisis:[118]

- A large number of nuclear installations whose functioning is not vital for the continued activity of the country, operated in particular by the French Alternative Energies and Atomic Energy Commission (CEA), Orano or the National Agency for the Management of Radioactive Waste (ANDRA), have been shut down and are maintained in safe state. Activities necessary for the functioning of the EDF nuclear power plants are nevertheless maintained.
- Examination work conducted by ASN in collaboration with its technical advisory body, the Institute for Radiological Protection and Nuclear Safety (IRSN), is continuing as normal. At the same time, on-site inspections are suspended, except when judged indispensable. On-site inspections are replaced by remote verifications, particularly concerning the examination of documents relating to day-to-day operation accompanied by audio-conferences with the licensee.

112 - Benjamin Mallet, "French nuclear plants tighten hygiene procedures over coronavirus worries", *Reuters*, 20 March 2020, see https://www.reuters.com/article/us-health-coronavirus-france-nuclear-idUSKBN2172J1, accessed 28 July 2020.

113 - EDF, "Fonctionnement du Parc nucléaire durant la période d'urgence sanitaire Covid-19", Presentation at the Plenary Meeting of HCTISN, Haut Comité pour la Transparence et l'Information sur la Sécurité Nucléaire, 16 June 2020 (in French), see https://www.hctisn.fr/article.php3?id_article=201, accessed 19 August 2020.

114 - Jean-Christophe Niel, Director General, IRSN, during a tele-video hearing at the National Assembly, 29 April 2020. In the middle of the hearing, Mr. Niel for over 2 minutes was unable to reconnect to the event, and the Assistant DG took the floor in the meantime. A lot of things can happen in a nuclear facility in 2 minutes.

115 - Marinette Valiergue, ASN spokesperson, personal communication, email to Mycle Schneider, 6 August 2020.

116 - Frédéric de Monicault, "Coronavirus: EDF fait tourner ses centrales avec moins de personnel présent", *Le Figaro*, 7 April 2020.

117 - *NIW*, "Nuclear Overseers Vary Response to Covid-19", 5 June 2020, op. cit.

118 - ASN, "In response to the Covid 19 epidemic, ASN is adapting its method of functioning while maintaining its rigour in the oversight of nuclear installations", Information Notice, 27 March 2020, see http://www.french-nuclear-safety.fr/Information/News-releases/Covid-19-epidemic-ASN-is-adapting-its-method-of-functioning-while-maintaining-its-rigour, accessed 28 July 2020.

- As part of the post-Fukushima safety improvements, EDF is updating its on-site emergency plans (Plan d'Urgence Interne or PUI) to include potential difficulties in gaining access to the sites, which could render full deployment of the local emergency response teams more complicated.

ASN later stated that the crisis management has been taking "a lot of time" (reorganization of work mode, regulatory adjustments, reinforced oversight, etc). On-site inspections remain impossible for the foreseeable future for inspectors that have a high-risk profile if with COVID-19. Major interregional inspections have been cancelled or delayed.[119]

By late March 2020, **IRSN** had limited "to the strict service necessities the mobility of its employees". Non-essential research activities and environment surveillance had been suspended (no environmental sampling was carried out).[120]

In the first week of the COVID-19 outbreak in France, **EDF** cut its staffing nuclear power plant sites by 70 percent, and even after the end of the lockdown in the middle of May 2020, staff reductions were at 50–60 percent on average. Mid-June 2020 was set as target date to get back to reference staffing levels.[121]

Some staff cuts were more significant. At the **Flamanville** site, for example—Units 1 and 2 are in outage since January 2019 and September 2019 respectively with major maintenance, and Unit 3 under construction—EDF reduced its staff level from 800 to 100. Only people in charge of safety and security remained on-site.[122] At Unit 3, the EPR, "all construction activities have been temporarily interrupted between mid-March and early May".[123] At the **Chooz** site—with one unit in operation and another one in decennial outage—EDF has reduced the number of workers on-site from 2,200 to 850.

The documentation requested by the French regulator from operators has been reduced to a minimum. ASN's Chief Inspector Christophe Quintin stated: "In general, we are requesting to see a great number of documents. Currently, we know that EDF's teams work in a just-in-time mode. Therefore, we are going to the essential."[124] ASN's President told the National Assembly at the end of April 2020:

> The resumption of the activities on-site, which will happen in a context of work overload because of the delays and in a disturbed context for the employees, with the accumulation of fatigue and stress, will have to be subjected to particular attention.[125]

119 - Christophe Quintin, "Les inspections de l'ASN pendant la crise COVID-19", Chief Inspector, ASN, Presentation at the HCTISN Plenary Meeting, Haut Comité pour la Transparence et l'Information sur la Sécurité Nucléaire, 16 June 2020 (in French), see https://www.hctisn.fr/IMG/pdf/Organisation_de_l_ASN_pendant_la_crise_COVID_cle8faa21.pdf, accessed 19 August 2020.

120 - IRSN, "COVID-19 : l'IRSN continue à assurer ses missions", 27 March 2020 (in French), see https://www.irsn.fr/FR/Actualites_presse/Actualites/Documents/IRSN_27032020_Mesures_Covid-19.pdf, accessed 16 August 2020.

121 - EDF, "Fonctionnement du Parc nucléaire durant la période d'urgence sanitaire Covid-19", Presentation at the Plenary Meeting of HCTISN, 16 June 2020, op.cit.

122 - Bate Felix, "France's EDF to reduce Flamanville nuclear plant staffing over virus", *Reuters*, 16 March 2020, see https://www.reuters.com/article/us-health-coronavirus-france-nuclear-idUSKBN21322Q, accessed 28 July 2020.

123 - 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 19 August 2020.

124 - Frédéric de Monicault, "Coronavirus: EDF fait tourner ses centrales avec moins de personnel présent", *Le Figaro*, 7 April 2020.

125 - Bernard Doroszczuk, President, ASN, during a hearing at the National Assembly, 28 April 2020 (in French), see http://www.senat.fr/compte-rendu-commissions/20200427/atdd.html#toc2, accessed 19 August 2020.

Mid-May 2020, ASN published a summary of activities during the lock-down period.[126] Between 15 March and 15 May 2020, "a total of 18 on-site inspections were carried out: twelve on safety and the possible consequences of the epidemic on the working of the facilities and six on labour inspectorate subjects". As a matter of comparison, in 2019, ASN carried out 1,800 inspections or 150 per month on average. In other words, during lockdown, ASN carried out only 6 percent of normal average inspections.

In the case of remote inspections, "ASN used new digital technologies, such as real-time and off-line remote-examination of the physical operating parameters of the reactors. Some of these innovations will be retained permanently." According to ASN, "both remote and on-site inspections confirmed that Orano and EDF were able to implement appropriate organisations to deal with the health risk (barrier measures, prevention plans) while maintaining the required level of safety".[127]

Considering the dramatically reduced level of on-site inspection and the large number of delayed outages and maintenance operations that is a remarkable statement.

The overall very positive reading of the French nuclear regulator clashes with the reporting of the sub-contractor organization Ma Zone Contrôlée that, in an open letter dated 12 July 2020 to the Minister for the Ecological Transition[128], in charge of nuclear oversight, claims that

- Until 27 April 2020, masks for contractors carrying out maintenance operations were not systematically available. "Numerous sub-contractor colleagues have experienced very humiliating and discriminatory situations, when, on certain sites, employees of the operators EDF/Orano had masks at the disposal to protect themselves against the virus but not us. Are we not equal?"
- Some contractors made use of their right to withdraw. All of them "were subjected to disgraceful pressures by their respective hierarchy, job blackmailing, disciplinary threats".
- The remote surveillance carried out by ASN on strictly regulatory and administrative aspects "makes us fear the worst". Several maintenance interventions were carried out without regulatory oversight under physical presence, as three-quarters of EDF staff were carrying out remote work.

Following a COVID-19 outbreak at the Belleville site, the contractor organization requests comprehensive testing on all sites, as they "all become potential clusters".[129]

This is not the first time that Ma Zone Contrôlée has alerted the authorities. In a letter to ASN dated 22 March 2020, they reported "large numbers of degraded working conditions and increasing worries of employees", including absence of hydroalcoholic gels and masks for sub-contractors, lack of systematic disinfection of exit radiation monitoring devices and dosimeters, impossibility to respect social distancing requirements in numerous places

126 - ASN, "ASN makes an assessment of its oversight since the beginning of lockdown", 25 May 2020, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-makes-an-assessment-of-its-oversight-since-the-beginning-of-lockdown, accessed 28 July 2020.

127 - Ibidem.

128 - Gilles Reynaud, President of Ma Zone Contrôlée, Letter to Barbara Pompili, Minister of Ecology, dated 12 July 2020, see http://www.ma-zone-controlee.com/lettre-ouverte-a-madame-la-ministre-b-pompili/, accessed 29 July 2020.

129 - Ibidem.

(shuttle buses, locker rooms, cafeterias…).[130] Three weeks later, the worker representatives sent a follow-up letter to ASN protesting against unequal treatment for sub-contractors compared to EDF/Orano staff now getting equipped with protective gear. While the entire country was in lock-down "hundreds of employees of sub-contractor companies returned at the request of client EDF in order to resume [work during] ongoing outages (Chooz, Civaux, Cattenom, Nogent, Dampierre)." The group, considering the "abundant feedback from the sites remains perplexed about the expected final good results of all ongoing interventions and their direct impacts on the level of safety and security".[131]

A particular point raised by the workers is the absence of usual oversight during interventions as a large share of EDF staff, including oversight personnel, was on telework. Reportedly, there were cases where intermediate checks during maintenance interventions were made over the phone. An accident on 9 April 2020 during the replacement of a hydrogen rack at Belleville-1 leaving two workers injured and leading to a fire that "could have had catastrophic consequences" [132] was clearly due to lack of oversight and "numerous deficiencies" of various types, as an ASN inspection revealed one week later.[133]

Some sub-contractor companies have refused to carry out certain work if the required conditions were not fulfilled. Workers from all parts of the country are hired for maintenance work and are often sharing housing with great contamination risks. They were not systematically tested. It is unclear whether this has changed as of the end of July 2020.

The regulator constantly juggles between safety concerns and operational necessities. On 30 July 2020, ASN granted EDF a delay for the second time (after February 2019) for the installation of emergency diesel generators for five reactors (Cattenom-4, Flamanville-1 and -2, Paluel-1 and -2). The new deadline for the Paluel site is 28 February 2021, just short of the tenth anniversary of the beginning of the Fukushima disaster. The extra emergency power supply was a requested measure in response to the Japanese catastrophe.

The **La Hague** spent fuel reprocessing plant was shut down for several weeks after employees executed their "right to withdraw" (droit de retrait), a legal right that allows them to refuse work under conditions they individually judge as dangerous. La Hague and fuel chain operator Orano experienced "severe disruptions in service activities" and "interruption of supply chain impacting CAPEX projects".[134]

Germany

According to the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU), nuclear oversight has continued to the extent deemed necessary. German nuclear operators carry out pandemic plans, which were adapted to the COVID-19 pandemic.

130 - Gilles Reynaud, Letter to the President of ASN, dated 22 March 2020.

131 - Gilles Reynaud, Letter to the President of ASN, dated 10 April 2020.

132 - Ibidem.

133 - In fact, the alternator presented a hydrogen leak detected in October 2019 but never repaired, which has led to the frequent need of storage tank replacement. ASN, Letter to the Director of the EDF Belleville Nuclear Power Plant, 23 April 2020 (in French), see https://www.asn.fr/content/download/170428/1748644/version/2/file/INSSN-OLS-2020-0702.pdf, accessed 31 July 2020.

134 - Philippe Knoche and David Claverie, "2020 Half-year results", Chief Executive Officer and Chief Financial Officer, Orano, 31 July 2020, see https://www.orano.group/en/finance/publications-and-regulated-information-credit-update, accessed 19 August 2020.

These include enhanced hygiene measures, stricter access control to the facility to identify possible infected personnel and rearrangement of working procedures to reduce working contacts to the minimum necessary.[135]

Until 2009, no clear regulation with respect to minimum workforce levels at nuclear facilities in Germany was in place. After an event in a German reactor, during which personnel from the control room had to perform duties in their secondary function in the fire-fighting brigade, the German Reactor Safety Commission (RSK) issued recommendations with respect to the determination of the minimum workforce needed for safe operation.[136] According to these recommendations, not including security staff, a minimum number of eight people have to be available on site at all times, five of which are control room staff. The determination of the minimum workforce required must take into account all potential states of the plant, including severe accidents. A corresponding requirement to determine the minimum workforce are since 2012 also included in German safety requirements for nuclear power plants.[137]

Major outages for nuclear power plants were planned for April and May 2020. The German regulatory authority had forbidden the maintenance and refueling outage of the nuclear power plant **Grohnde** as originally planned. The shutdown and related activities would have necessitated about 1,000 additional staff beyond the 500 permanent employees for a period of two weeks at the plant site. The outage was then reorganized and took an additional three weeks, while restricting the necessary workforce to a maximum of 250. The reactor was reconnected to the grid on 24 May 2020. Systematic testing for COVID-19 was carried out and no contamination was identified.[138] It was expected that the schedule of planned outages at other plants would also change accordingly.

Transports of highly radioactive wastes from the Sellafield reprocessing plant in the U.K., planned for the spring of this year, have been postponed, as the required corresponding police operation was not feasible.[139]

Hungary

Measures

In Hungary, the scope of planned 2020 outage activities have been reduced mainly due to travel restrictions of foreign vendor companies.

135 - BMU, "Gewährleistung der nuklearen Sicherheit während der Corona-Krise - BMU-Meldung", Bundesministerium für Umwelt, Naturschutz und Nukleare Sicherheit, 27 March 2020 (in German), see https://www.bmu.de/ME9001, accessed 31 July 2020.

136 - RSK, "Anforderungen an die Bestimmung der Mindestschichtbesetzung in Kernkraftwerken zur Gewährleistung einer sicheren Betriebsführung", Reaktor-Sicherheitskommission, Recommendation of the Reactor Safety Commission, 417th Meeting, 18 June 2009 (in German), see www.rskonline.de/sites/default/files/reports/epanlagersk417hp.pdf, accessed 15 August 2020.

137 - BfS, "Safety Requirements for Nuclear Power Plants", Bundesamt für Strahlenschutz, Edition 03/15, 3 March 2015.

138 - Preussen Elektra, "Revision in Zeiten von Corona: Verlängerter Anlagenstillstand des Gemeinschaftskernkraftwerks Grohnde beendet", 24 May 2020 (in German), see https://www.preussenelektra.de/de/unser-unternehmen/newsroom/pressemitteilungen/2020/verlaengerteranlagenstilllstandkwgbeendet.html, accessed 2 August 2020.

139 - BMU, "Gewährleistung der nuklearen Sicherheit während der Corona-Krise—BMU-Meldung", 27 March 2020, op. cit.

Japan

Infections

No systematic information is available.

Three people, including one employee's family member, were infected at TEPCO's Kashiwazaki Kariwa plant, and two employees were contaminated at its headquarters, interrupting the safety upgrading work to resume.[140] Kyushu Electric Power Company's Genkai plant is constructing a facility for dealing with severe accidents. In April 2020, two workers were confirmed to be contaminated. Consequently, about 300 workers were instructed to remain on standby at home and construction was suspended.[141]

As of 1 July 2020, there were no reports about workers infected with COVID-19 within the Fukushima Daiichi Nuclear Power Plant.[142] As countermeasures for contamination, workers are obliged to have their temperature taken and wear a mask, but officially no change has been made to the decommissioning plan.[143]

The evacuation plan for nuclear accidents (nuclear disaster prevention guidelines) formulated after the Fukushima accident does not include measures against infectious diseases at evacuation centers. Therefore, the Cabinet Office decided to include infectious disease control measures in the guidelines in the future.[144]

Mexico

Measures and Impacts

The level of maintenance staff on shift was optimized to the level necessary to complete the minimum preventive and corrective maintenance activities.

Netherlands

Certain work scheduled for the country's only nuclear reactor Borssele's annual refueling and maintenance, which began on 29 May 2020, has been postponed until the next planned outage in 2021.[145]

140 - TEPCO, "Implementation of additional measures to prevent the spread of the novel coronavirus infection", Press Release, 27 April 2020 (in Japanese), see https://www.tepco.co.jp/kk-np/data/press/pdf/2020/2020042701p.pdf, accessed 15 May 2020.

141 - Genkai Town, "Message from the Mayor", 21 April 2020 (in Japanese), see http://www.town.genkai.lg.jp/site/korona/35850.html, accessed 15 May 2020.

142 - TEPCO, "Covid-19 Countermeasures at the Fukushima Daiichi Nuclear Power Station", 2 July 2020, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/reference/pdf/2020/reference_20200702_01-e.pdf, accessed 21 July 2020.

143 - Ibidem; and TEPCO, "Measures against the novel coronavirus at Fukushima Daiichi Nuclear Power Station", 28 May 2020 (in Japanese), see https://www.tepco.co.jp/decommission/common/images/d200528_12-j.pdf, accessed 15 May 2020.

144 - *NHK*, "Evacuation plan for nuclear accidents: Considering measures against infectious diseases", 14 May 2020 (in Japanese) see https://www3.nhk.or.jp/news/html/20200514/k10012429081000.html, accessed 15 May 2020.

145 - EPZ, "Nuclear power plant out of service for annual maintenance", 14 April 2020, see https://epz.nl/actueel/kerncentrale-uit-bedrijf-voor-jaarlijks-onderhoud-1, accessed 10 June 2020.

Romania

Measures and Impacts

In April 2020, the planned overhaul of Cernavoda-1 was delayed. This would have been done during a planned maintenance which is performed every two years, during May and June and usually lasts 30 days.[146] The outage has been delayed and started only 20 June 2020. The unit was reconnected to the grid 4 August 2020 after an extended outage.[147]

Russia

Infections

In a quite unique manner, Rosatom's Director General Alexey Likhachev has been doing weekly video updates for months on numbers and locations of positive cases and recovered staff[148] (see Figure 20)[149]. Cumulating active and recovered cases on the graphic illustration presented by Rosatom on 31 July 2020, the order of magnitude of total infections appears to be around 4,500, a very large number compared to any other reported COVID-19 incidence at a nuclear operator (e.g. about 600 at EDF). And while EDF has reported hardly any active cases as of middle of June 2020, Rosatom still accounted for around 1,200 ill people as of the end of July 2020.

Figure 20 · Rosatom's DG Presenting a Weekly Overview of COVID-19 Cases at Rosatom

Source: Screenshot—Rosatom, "Обращение главы «Росатома» А.Е. Лихачёва (31 июля 2020)", 31 July 2020

Note: Active (Red) and Recovered (Green) COVID-19 Cases at Rosatom as of 30 July 2020.

146 - *Serbia Energy News*, "Romania: Maintenance of NPP Cernavoda's unit 1 postponed", 10 April 2020, see https://serbia-energy.eu/romania-maintenance-of-npp-cernavodas-unit-1-postponed/, accessed 18 May 2020.

147 - *SeeNews*, "Romania's Nuclearelectrica re-synchronizes Cernavoda NPP's Unit 1 to grid", 6 August 2020, see https://seenews.com/news/romanias-nuclearelectrica-re-synchronizes-cernavoda-npps-unit-1-to-grid-709048, accessed 26 August 2020.

148 - NIW, "Nuclear Overseers Vary Response to Covid-19", 5 June 2020.

149 - Rosatom, "Обращение главы «Росатома» А.Е. Лихачёва (31 июля 2020)", 31 July 2020 (in Russian), see https://www.atomic-energy.ru/video/105932, accessed 16 August 2020.

In April 2020, Rosatom raised concerns about the spread of the virus in the three "nuclear cities" which host civil and military nuclear research. But no numbers were released.[150] On 1 April 2020, Rosatom announced that four of its employees tested positive for COVID-19 but did not specify the location.[151] Consequently, at the **Beloyarsk** site, after one worker's wife fell ill, all employees were asked to move to special dispensaries and commute from there.

Measures and Impacts

On 26 March 2020, Rosatom issued a statement on its COVID-19 response:

> At present, we have introduced additional measures at all of Russia's nuclear power plants, including regular health check-ups of our personnel. We have arranged for as many employees as possible to work remotely and purchased personal protective equipment and hygiene-related products in bulk; we are constantly disinfecting our production facilities and vehicles and have essentially cancelled all business trips. We are monitoring our employees' health in close cooperation with local authorities across our areas of operation. We have developed a number of additional contingency plans for various scenarios of the coronavirus pandemic that may have an effect on the health of our NPP [nuclear power plant] employees.[152]

A few days later, Rosatom subsidiary Rosenergoatom announced that nuclear power plant staff would be isolated from the general public and required to live onsite at their respective stations.[153] In addition:

> [Rosatom] has created a kind of 'mirror-management' system so that if one manager falls ill with the virus, or any other sickness for that matter, their 'duplicate' can step in and continue managing the project or operation.[154]

However, apparently, central management leaves broader decisions about staff quarantines up to local authorities both in the Russian regions where Rosatom operates facilities as well as in other countries. On 6 April 2020, it pulled 178 of its employees from the **Rooppur** construction site in Bangladesh. Rosatom stated: "When our employees find themselves abroad in this difficult situation and want to return to their homeland, we will accommodate their needs."[155]

As more than 4,000 people are working at the site, Rosatom assumes no impact on the planned schedule for the project because of the temporary relocation of its employees. It further cites enhanced health care measures to protect people at the construction site, like measuring employees' temperatures, special disinfection of all office space and the issuing of masks to all employees.[156] But the withdrawal of such a large number of Russian staff, many of whom can

150 - Tom Balmforth, "Coronavirus threatens workforce in Russia's nuclear cities - Rosatom", *Reuters*, 28 April 2020, see https://www.reuters.com/article/health-coronavirus-russia-nuclear-idUSL5N2CG5CY, accessed 16 May 2020.

151 - Charles Digges, "Four nuclear workers test positive for coronavirus as Rosatom steps up pandemic response", Bellona, 1 April 2020, see https://bellona.org/news/nuclear-issues/2020-04-some-russian-nuclear-workers-isolated-as-rosatom-steps-up-coronavirus-response, accessed 1 August 2020.

152 - Rosatom, "ROSATOM Director General Makes Statement on COVID-19 Situation", 26 March 2020, see https://rosatom.ru/en/press-centre/news/rosatom-director-general-makes-statement-on-covid-19-situation/, accessed 1 August 2020.

153 - Charles Digges, "Russia's nuclear workers isolated onsite as coronavirus spreads", Bellona, 3 April 2020, see https://bellona.org/news/nuclear-issues/2020-04-russias-nuclear-workers-isolated-onsite-as-coronavirus-spreads, accessed 1 August 2020.

154 - *NIW*, "Nuclear Overseers Vary Response to Covid-19", 5 June 2020, op. cit.

155 - Rosatom, "ROSATOM arranged the return of 178 employees from construction site of Rooppur NPP (Bangladesh) to Russia", 7 April 2020, see https://www.rosatom.ru/en/press-centre/news/rosatom-arranged-the-return-of-178-employees-from-construction-site-of-rooppur-npp-bangladesh-to-rus/, accessed 1 August 2020.

156 - Ibidem.

be presumed to be working at higher oversight responsibility levels, means that there could be questions about how safely construction is being carried out.

Slovakia

Fuel loading of **Mochovce-3**, under construction since 1985, has been further delayed. Just prior to the COVID-19 pandemic, it was expected at the beginning of the summer of 2020 with "in the worst case, it will be the end of 2020".[157] However, this schedule will not hold, as due to social distancing measures the number of workers allowed on the site halved in March 2020., even if it was said that "the situation gradually stabilized in April and May".[158] The national regulator said in May 2020 that "it is impossible to estimate a precise delay for commissioning of the third nuclear unit."[159]

Slovenia

Measures and Impacts

The Krsko nuclear power plant is considered a critical energy infrastructure facility. Following the declaration of the COVID-19 pandemic, the operator reduced the activities to "providing only those functions that are necessary to ensure the safe and stable operation of the plant".[160]

South Korea

Infections

As of 1 July 2020, there were no reported cases of COVID-19 affected personnel working at South Korea's nuclear power plants. Two employees, one working at the headquarters of the nuclear operator and one security guard, were infected, and there were no reported cases of *transmission* in nuclear power plants.[161]

Measures and Impacts

Schedule and duration of at least one unspecified reactor outage was adjusted to ensure worker safety.

157 - Slovenske Elektrarne, "Mochovce 3: Nuclear authority issued a draft decision on fuel loading", 18 February 2020, see https://www.seas.sk/article/mochovce-3-nuclear-authority-issued-a-draft-decision-on-fuel-loading/409, accessed 23 April 2020.

158 - *vEnergetike.sk*, "Completion of Mochovce NPP may be delayed again", *Webnoviny.sk*, 18 May 2020, see https://www.webnoviny.sk/venergetike/completion-of-mochovce-npp-may-be-delayed-again/, accessed 27 June 2020.

159 - *vEnergetike.sk*, "Mochovce NPP will be delayed, UJD confirms", 26 May 2020, see https://www.webnoviny.sk/venergetike/mochovce-npp-will-be-delayed-ujd-confirms/, accessed 9 June 2020.

160 - Eurelectric, "Impact of COVID 19 on Customers and Society—Recommendations from the European Power sector", Updated 31 March 2020, see https://cdn.eurelectric.org/media/4313/impact_of_covid_19_on_customers_and_society-2020-030-0216-01-e-h-E7E407BA.pdf, accessed 20 August 2020.

161 - NSSC, "The NSSC Chairperson Visited Nuclear Power Plant to Check Response Against COVID-19", Press Release, 26 May 2020, 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=45924&USER_NAME=&TEL_NO=&WRITER_DI=&_csrf=&SEARCH_FLD=&SEARCH, accessed 3 June 2020.

Measures at the Regulator

Meetings of the Nuclear Safety and Security Commission (NSSC) have been held with limited face-to-face interactions since 10 April 2020 by minimizing the number of attendees, checking body temperatures, wearing masks and physically distancing (maintaining a distance of 2 meters) from each other. The head of the national regulator stated: "The NSSC will strictly comply with the hygiene rules suggested by the disease control authorities and try to ensure that safety regulations and nuclear power plant operation are normally conducted."[162]

Spain

Measures and Impacts

Trillo-1 was taken offline for a refueling outage while the operator limited the number of workers onsite, resulting in an outage extension to 35 days.

"Low wholesale electricity prices in Spain mean the country's fleet of seven power reactors is currently operating at a loss", the Spanish Nuclear Forum said in a statement on 13 May 2020. The nuclear lobby group has urged a review of the fiscal regime under which the reactors operate.[163]

Market prices are depressed by the COVID-19 pandemic and are "failing to cover the operating costs of the Spanish nuclear plants, not even the amount they pay in taxes and levies which amount to €22/MWh (about US$24/MWh)", Foro Nuclear President Ignacio Araluce said in the statement.[164]

Sweden

Infections

The national regulator, the Swedish Radiation Safety Authority (SRSA), reported in June 2020, that it had "so far seen few COVID-19 cases at plant sites". [165] However, there are no precise numbers.

Measures and Impacts

Measures included isolating control room staff and essential personnel, relatively isolated sites and on-site housing for traveling workers during refueling outages.[166]

162 - NSSC, "Chairperson Uhm Had Virtual Meeting With Heads of Regulatory Agencies of Other Major Nuclear Countries to Discuss COVID-19 Responses", Press Release, 7 May 2020, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?MENU_ID=90&CONTENTS_NO=&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45920&P_BBS_SEQ=&CATE_SEQ=&pageNo=2&SEARCH_SEQ=&SEARCH_FLD=&SEARCH=&PREV_IDX=45922&NEXT_IDX=45920&MODULATE_KEY=%242a%2410%24UIapasTfrqWHlufhAJH5iuiIwluEWqGqiXSoLpT2RVPAzo1O3DUn6&_csrf=, accessed 1 August 2020.

163 - Gianluca Baratti, "Spain's power reactors failing to cover operating costs: Foro Nuclear", *Nucleonics Week*, 21 May 2020.

164 - Ibidem.

165 - *NIW*, "Nuclear Overseers Vary Response to Covid-19", 5 June 2020, op. cit.

166 - Ibidem.

United Arab Emirates

Measures and Impacts

Majority owner Emirates Nuclear Energy Corporation (ENEC) has introduced measures such as locking down the **Barakah** site with four units under construction[167] and halting "non-essential" work in the wake of the pandemic.[168] Additionally, ENEC's Nawah company, the subsidiary responsible for Barakah's operation and maintenance, issued guidelines to reduce the number of workers at the plant and enforce social distancing. Besides following strict quarantine and other preventative procedures at Barakah, UAE's nuclear regulator, the Federal Authority for Nuclear Regulation (FANR) and ENEC have also established critical staff and functions to manage a potential second-wave of COVID-19.[169]

Measures at the Regulator

FANR established a COVID-19 crisis management taskforce, which called for measures such as asking employees to work remotely, leveraging digital means to conduct inspection and monitoring activities, and reducing the number of on-site inspectors.[170]

United Kingdom

Infections

No comprehensive information is available. A Chinese national working at the Hinkley Point C construction site tested positive for COVID-19 in early March 2020. Four of his co-workers self-isolated but were later tested negative and have returned to work.[171] Mid-March 2020, a staff member of the Sellafield nuclear site had tested positive, followed by another employee with suspected COVID-19 a day or two later who had begun self-isolation. Within days, the number of Sellafield employees self-isolating climbed to about 1,000. The Sellafield complex has approximately 11,500 staff. In late March 2020, the operator decided to shut down the Magnox reprocessing plant at the site.[172] It only resumed full operation in the first week of August 2020.[173]

EDF Energy mentioned in an 8 June 2020 statement the "tragic passing of one of our own employees from COVID-19 in April" at Hinkley Point B.[174] In late July 2020, the entire plant

167 - Barakah-1 went critical on 1 August 2020.

168 - *WNN*, "ENEC CEO: Barakah Plant to Start up 'Very Soon'", 7 May 2020, see https://world-nuclear-news.org/Articles/ENEC-CEO-Barakah-to-start-up-very-soon, accessed 14 May 2020.

169 - *NIW*, "Nuclear Overseers Vary Response to Covid-19", 5 June 2020, op. cit.

170 - Christer Viktorsson, "Viewpoint: Regulators are adapting to an unprecedented challenge", *WNN*, 11 May 2020, see https://world-nuclear-news.org/Articles/Viewpoint-Regulators-adapt-to-an-unprecedented-cha, accessed 11 May 2020.

171 - *Global Construction Review*, "Covid-19 hits UK's Hinkley Point C nuclear project", 6 March 2020, see http://www.globalconstructionreview.com/news/covid-19-hits-uks-hinkley-point-c-nuclear-project, accessed 2 August 2020.

172 - Jillian Ambrose, "Sellafield nuclear waste site to close due to coronavirus", *The Guardian*, 18 March 2020, see https://www.theguardian.com/business/2020/mar/18/sellafield-nuclear-waste-plant-close-coronavirus-staff, accessed 2 August 2020.

173 - Sellafield Ltd, "Green light to restart Magnox Reprocessing", 3 August 2020, see https://www.gov.uk/government/news/green-light-to-restart-magnox-reprocessing, accessed 30 August 2020.

174 - EDF Energy, "Letter to the Hinkley Site Stakeholder Group - 8 June 2020", 8 June 2020, see https://www.edfenergy.com/media-centre/news-releases/letter-hinkley-site-stakeholder-group-8-june-2020, accessed 2 August 2020.

of a key concrete supplier for the construction at Hinkley Point C was closed after 22 of the 90 employees tested positive.[175]

Measures and Impacts

According to the U.K. Office for Nuclear Regulation (ONR), "all sites have minimum staffing levels, and contingency plans should they fall below these levels, to enable them to remain in control of activities that could impact on nuclear safety under all foreseeable circumstances, including pandemic disease."[176] In correspondence with independent experts, an ONR representative stated early March 2020 that "staff rotas [schedules] at nuclear sites are resilient to keep generation running in scenarios including pandemic or industrial action. If a generating site needed to be shut down for any reason, it would be shut down safely."[177]

Figure 21 · Canteens at Hinkley Point C – Before and After Social Distancing

Photos: Canteens at Hinkley Point C, before and after social distancing measures, both pictures are from late March 2020. A local paper quoted workers as saying: "They've done their best, but when anybody moves, they're inevitably immediately within two metres of someone else."[178]

In early June 2020, EDF Energy described measures applied by and by at their nuclear sites[179] including:

- Introducing remote working and split shift arrangements in a safe and controlled way, which has reduced the overall daily footfall on the site by over 50 percent;
- Determining the level of risk associated with vulnerable and high-risk employees and bringing in appropriate measures to support them;

175 - *BBC*, "Concrete plant closed after Covid-19 outbreak", 27 July 2020, see https://www.bbc.com/news/uk-england-bristol-53555062, accessed 2 August 2020.

176 - ONR, "Coronavirus (COVID-19) - ONR Position [26/03/20]", Office for Nuclear Regulation, 17 March 2020, Update issued 26 March 2020, see http://news.onr.org.uk/2020/03/coronavirus-covid-19-onr-position/, accessed 1 August 2020.

177 - David Lowry, "Corona-crisis Hits Nuclear Sector", *Energy Transition*, 9 April 2020, see https://energytransition.org/2020/04/corona-crisis-hits-nuclear-sector/, accessed 2 September 2020.

178 - *The West Country*, "Social distancing fears in Hinkley Point C canteen despite EDF's best efforts", see https://www.thisisthewestcountry.co.uk/news/somerset_news/18330262.social-distancing-fears-hinkley-point-c-canteen-despite-edfs-best-efforts/, accessed 2 August 2020.

179 - EDF Energy operates all 15 U.K. nuclear reactors.

- Increasing hygiene and cleaning arrangements in high footfall areas and introducing social distancing measures across the site;
- The installation of thermographic cameras at the entrance and the purchase of COVID-19 immunity test kits.[180]

However, unlike at home, in France, where EDF rescheduled a large number of outages, subsidiary EDF Energy went through with several refueling and maintenance outages, including at Hartlepool-2 and Heysham-2.

Even after social distancing measures had been implemented, several environmental NGOs and Local Authorities were not convinced and, in a letter dated 30 March 2020, urged ONR "to exercise your powers and responsibilities to close operations at Hinkley Point C until such time as work can be safely resumed".[181] Only two days later, national television news (*ITV*) quoted a worker as saying: "At the moment I feel like the project is being put before my safety, my family's safety and everybody on that site's safety. You've still got people in vans - three and up - and all the toilets are rammed. There's an account that I know of where someone's been sent home with symptoms and the whole of their workforce - (the people) they work with and have had prolonged contact with - have been told not to isolate." An EDF Energy spokesperson told ITV, it would be like everywhere else: "We're actually learning as we go".[182] This sounds a bit different from the "all prepared" message that ONR has been putting out from the start.

On 23 July 2020, EDF Energy issued an update to its COVID-19 measures at the Hinkley Point C construction site:

> That means that social distancing, the use of protective screens and extra cleaning continue on the site and in our canteens and buses. Workers will continue to have their temperature taken before entering the site. Face masks are mandatory on our external busses, as they are on public transport in the rest of the country. Bus services for workers are focused on our park and ride sites and we are no longer picking up workers in the community. We are looking to expand our testing capacity and aim to be able to test new starters for Coronavirus. We are not planning for a full return to offices for those that have been successfully working from home. This will help us maintain social distancing.[183]

While the workforce at the Hinkley Point C site was cut to about 2,000 in March–April, by July 2020 levels were back at 4,500, almost pre-crisis levels.

Measures at the Regulator

While dealing with significant restrictions at the nuclear facilities and at their own organization, The Office for Nuclear Regulation (ONR) remained confident all along:

180 - EDF Energy, "Letter to the Hinkley Site Stakeholder Group - 8 June 2020", June 2020, op. cit.

181 - NFLA, "NGO Forum Co Chairs and NFLA Secretariat issue letter over the ongoing construction work at Hinkley Point in Somerset", Nuclear Free Local Authorities, 31 March 2020, see https://www.nuclearpolicy.info/news/ngo-forum-co-chairs-and-nfla-secretariat-issue-letter-ongoing-construction-work-hinkley-point/, accessed 2 August 2020.

182 - *ITV*, "Continued concerns over conditions at Hinkley Point C amid coronavirus pandemic", 1 April 2020, see https://www.itv.com/news/westcountry/2020-04-01/worker-at-hinkley-point-c-near-bridgwater-says-edf-is-putting-construction-project-ahead-of-staff-safety, accessed 2 August 2020.

183 - EDF Energy, "Coronavirus update from Hinkley Point C - 23 July", 23 July 2020, see https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/news-views/coronavirus-update-hinkley-point-c-july-23, accessed 2 August 2020.

On 26 March 2020

A number of inspectors will continue to travel to sites where required, but we will carry out as much of our business as possible via phone, email and Skype. These measures will not have a severe impact on the effectiveness of our regulation of the nuclear industry.[184]

On 25 June 2020

We remain satisfied with industry's response at this time and there has been no significant change to dutyholders' safety and security resilience.

(…)

ONR staff continue to work at home, primarily. We have considered our priorities, deferred non-critical activities, and are carrying out as much of our work as possible via videoconference, phone and email.

We are inspecting, assessing and permissioning [?] remotely so far as is practicable, although we continue to go to site, as key workers, to conduct urgent and essential regulatory business, in accordance with public health measures.[185]

United States

Infections

No systematic information on COVID-19 cases in the U.S. nuclear industry or its regulator is available, therefore WNISR only reports on a selection of documented examples. It appears that in a few cases, the outbreak was so large that it was impossible to avoid communication.

DTE Energy's **Fermi-2** in Michigan, in the middle of a refueling outage with more than 2,000 workers on-site, reportedly may have had 200–300 positive COVID-19 cases in May 2020, which might have been the largest outbreak at any single place in Michigan. DTE has refused to disclose the number of positive cases among its workforce.[186] But DTE did confirm that large-scale testing had begun early May 2020 and by 11 May 2020 it had requested exemptions from work-hour controls (see hereunder).

At the **Limerick-1** plant in Pennsylvania, two workers tested positive in the days prior to a refueling and maintenance outage began on 27 March 2020, and three additional workers in the days after the outage started. Following these infections, an additional 44 of around 1,400 workers on-site were quarantined, with more than half of the quarantined personnel presenting symptoms of the virus.[187]

On 1 April 2020, operator Exelon confirmed the first case at its **Quad Cities** plant. [188]

184 - ONR, "Coronavirus (COVID-19) – ONR Position [26/03/20]", 17 March 2020, op. cit.

185 - ONR, "COVID-19 (coronavirus) – ONR Position", 25 June 2020, see http://news.onr.org.uk/2020/06/covid-19-coronavirus-onr-position/, accessed 2 August 2020.

186 - *NIW*, "Massive Covid-19 Outbreak at Fermi-2", 15 May 2020.

187 - Andrew Maykuth, "More Limerick Nuclear Plant Workers Test Positive for Coronavirus; Refueling to Continue", *The Philadelphia Inquirer*, 8 April 2020, see https://www.inquirer.com/business/limerick-nuclear-plant-refueling-coronavirus-workers-infected-20200408.html, accessed 1 September 2020.

188 - ANS, "Coronavirus makes its way into U.S. nuclear plants", American Nuclear Society, 10 April 2020, see https://www.ans.org/news/article-85/coronavirus-makes-its-way-into-us-nuclear-plants/, accessed 27 July 2020.

On 4 April 2020, a contractor working at the **Susquehanna** two-unit plant, in Berwick, Pennsylvania, prior to the Unit 1 spring refueling outage tested positive for COVID-19 and self-quarantined. Seven people who came into contact with the infected individual were also quarantined.[189]

In early May 2020, ten workers at the **Waterford** nuclear power plant had tested positive for COVID-19. Some of the 750 workers that were brought in for the refueling outage told reporters they don't think enough is being done to protect their health amid the pandemic.[190]

Another major outbreak was reported at the **Vogtle** construction site in Georgia. The first case was confirmed on 6 April 2020. On 15 April 2020 it was announced that a "lower productivity levels and a slower pace of completion prompted a 20% workforce reduction".[191] Nonetheless, three weeks after the first confirmed case, as of 28 April 2020, 153 workers had been tested positive for COVID-19.[192] By mid-June 2020, more than 200 positive cases were reported.[193] As of 2 September 2020, while the number of infections were reported to be declining, more than 800 workers on the project had been tested positive with over 100 active cases.[194] On 10 July 2020, Tom Fanning, President and CEO of the builder's parent company Southern tested positive.[195]

The **Millstone** plant, in Connecticut, had a first confirmed case of COVID-19 prior to the beginning of its refueling outage in early April 2020, which drew 750 temporary workers onsite, sparking concern and criticism from Millstone employees towards insufficient measures put in place, including lack of personal protective equipment, cleaning and sanitizing.[196] In early May 2020, Dominion reported 10 employees had tested positive.[197] On 18 May 2020, it was revealed that 11 workers had tested positive, three of whom were control room operators.[198]

Measures and Impacts

The industry lobby organization Nuclear Energy Institute (NEI) listed a number of measures taken, which have been quite typical for any nuclear country:

> Utilities are taking actions to limit the potential for infections, such as implementing teleworking where appropriate, practicing responsible social distancing both at work and

189 - Ibidem.

190 - *News 8*, "10 workers at Waterford nuclear power station site test positive for coronavirus", *wtnh.com*, 5 May 2020, see https://www.wtnh.com/news/connecticut/new-london/10-workers-at-waterford-nuclear-power-station-site-test-positive-for-coronavirus/, accessed 27 July 2020.

191 - *NIW*, "Covid-19 Cases Lead to 20% Workforce Reduction at Vogtle", 1 May 2020.

192 - *News Channel 6*, "Updated COVID-19 case numbers for Plant Vogtle", *WJBF*, 29 April 2020, see https://www.wjbf.com/lifestyle/health/coronavirus/plant-vogtle-reports-first-positive-coronavirus-case/, accessed 2 July 2020.

193 - *NIW*, "Vogtle Cost Up Another $1 Billion With 80% Component Failure Rate", 12 June 2020.

194 - Matt Kempner, "Georgia nuclear project reports more than 800 COVID-19 cases to date", *The Atlanta Journal-Constitution*, 1 September 2020, see https://www.ajc.com/ajcjobs/georgia-nuclear-project-reports-more-than-800-covid-19-cases-to-date/P4BXNDI5ONHX7BSPCPTJYZNWYE/, accessed 2 September 2020.

195 - ANS, "Southern CEO tests positive for COVID-19", 14 July 2020, see https://www.ans.org/news/article-343/southern-ceo-tests-positive-for-covid19/, accessed 2 September 2020.

196 - Sten Spinella, "Millstone security employees criticize COVID-19 safety efforts", *The Day*, 3 May 2020, see https://www.theday.com/article/20200503/NWS01/200509848, accessed 3 September 2020.

197 - *NIW*, "The Widening Impact of COVID-19", 8 May 2020.

198 - Sten Spinella, "Millstone's positive COVID-19 cases include control room operators", *The Day*, 24 May 2020, see https://www.theday.com/business/20200524/millstones-positive-covid-19-cases-include-control-room-operators, accessed 3 September 2020.

home, and screening personnel allowed on-site. Specific actions by each plant will vary based on the condition at that plant and its plant status. These actions may include, but are not limited to:

▸ mechanisms to maintain awareness and communicate with staff;

▸ telling workers who don't feel well to stay home and encourage them to seek medical attention, liberalizing the sick-leave policy, developing or updating a policy on telecommuting;

▸ setting up a screening point before people can enter the plant, to identify people who have symptoms;

▸ making masks, hand sanitizer and gloves available within a plant to places where they will be needed;

▸ focusing on extra disinfection of common areas;

▸ using paperless work processes to reduce human contact and teleconferencing when possible.[199]

While nuclear operators have identified some tasks that can be done remotely or be postponed, some employees must still come to nuclear power plants on a daily basis because many computers are not connected to the internet (so-called airgap). This is a cybersecurity measure required in operations by the NRC in order to prevent hackers from accessing critical computer systems.[200]

Figure 22 · Travel Trailers at the Cook Nuclear Plant—Just in Case

Photo: Bill Downey, Cook Nuclear Plant, 2020

Based on pandemic plans established a decade ago, at least part of the nuclear plants have cots, blankets, chemical toilets and enough personal care items to sustain the operating crews at

199 - NEI, "The Nuclear Industry's Response to the Coronavirus (COVID-19)", Nuclear Energy Institute, 1 April 2020, see https://www.nei.org/news/2020/nei-coronavirus-covid-19-response, accessed 27 July 2020.

200 - For an example of a cyber-attack on a nuclear power plant, see M.V. Ramana and Lauren J. Borja, "The Computer Infection of Kudankulam and its Implications", *The India Forum*, 10 January 2020, see https://www.theindiaforum.in/article/computer-infection-kudankulam-and-its-implications, 10 January 2020.

a plant for several weeks should such measures be necessary.[201] Officials have suggested they might isolate critical technicians at the country's nuclear power plants and ask them to live onsite to avoid exposure to the virus. In early April 2020, Cook Nuclear Plant staff prepared about 80 travel trailers available through employees on the parking lot of the site—just in case.[202]

In reality, the measures have gone deep into work management. Following the large COVID-19 outbreak at **Fermi-2** (see above), on 11 May 2020, DTE submitted a letter to the NRC seeking significant exemptions from work-hour controls for staff, pledging that "these controls ensure that covered workers are subjected to the following minimum controls" [203]. Three days later, the NRC granted *exactly* what the industry had asked for:

- Individuals will work up to 16 work hours in any 24-hour period and up to 86 work hours in any 7-day period, excluding shift turnover;
- A minimum 10-hour break is provided between successive work periods;
- 12-hour shifts up to 14 consecutive days;
- A minimum of 6 days off are provided in any 30-day period; and
- Requirements have been established for behavioral observation and self-declaration during the period of the exemption.[204]

The Fermi-2 decision was not isolated. Between 3 April and 14 May 2020, the NRC granted similar exemptions, typically for two months, from work-hour controls for at least 14 reactors (Beaver Valley-1&2, Braidwood-1&2, Fermi-2, Ginna, Limerick-1&2, Palo Verde-1&2&3, Quad Cities-1&2, Seabrook-1).[205]

These are major exemptions to standard rules for essential staff members in the following key workforce categories: operators, health physics and chemistry, fire brigade, maintenance and security. Challenges to safety and security through additional stress and fatigue are likely under those conditions.

The NRC has developed an ad-hoc process to review work hour limits, because the existing regulations never considered a pandemic. Using existing exemption provisions, the NRC will approve requests with minimal initial review. Industry observers pointed out that this "suggests that a certain amount of guesswork—and subjectivity—will be involved in decision-

201 - Iulia Gheorghiu, "Coronavirus could disrupt normal refueling practices for nuclear facilities as staffing concerns grow", *Utility Dive*, see https://www.utilitydive.com/news/coronavirus-could-disrupt-normal-refueling-practices-for-nuclear- facilities/574920/, 26 March 2020.

202 - Alexandra Newman, "Cook Nuclear Plant ready if critical employees can't go home", *The Herald Palladium*, 3 April 2020, see https://www.heraldpalladium.com/news/cook-nuclear-plant-ready-if-critical-employees-cant-go-home/article_5af88489-29c1-5f8e-9666-035eff63bfbe.html, accessed 27 July 2020.

203 - Peter Dietrich, DTE, Letter to NRC, 11 May 2020.

204 - NRC, Letter to Peter Dietrich, DTE, 14 May 2020, see https://www.nrc.gov/docs/ML2013/ML20133K055.pdf, accessed 27 July 2020.

205 - Office of Nuclear Reactor Regulation, "COVID-19 Regulatory Activities for Nuclear Reactors—10 CFR Part 26 Work Hour Requirements", U.S.NRC, Updated 27 May 2020, see https://www.nrc.gov/about-nrc/covid-19/reactors/part-26-work-hour-req.html, accessed 27 July 2020.

making, with outside observers and critics left mostly in the dark about how decisions are being made".[206]

As Fermi-2 was shut down on 21 March 2020 and had not returned to service by 24 July 2020, the 4-month outage is one of the longest in the plant's history, and the longest since a major fire left the plant seriously damaged in 1993.[207]

Tennessee Valley Authority (TVA) has been scaling back some of its planned maintenance work at **Watts Bar** to limit the number of individuals on site and is performing health screenings of all TVA employees and contractors coming to the plants.

Limerick-1 owner/operator Exelon presented the refueling outage as exemplary—and quite the opposite of the Fermi-2 case. Lasting from 27 March to 13 April 2020, it was completed in a plant-record 16 days, and no additional COVID-19 infections were reported *during* the outage. A contractor told media a different story. On 3 April 2020—in the middle of the outage—he claimed that social distancing was not in place:

> From the first day I got there, there were no less than 100 people in the training room being processed. I have pictures from that day of people literally sitting on top of each other, no one enforcing social distancing. There were computer labs for people to take the tests they need to get into the plant, people sitting at every computer elbow to elbow. So, I've been concerned since the minute I walked in there.[208]

Measures Taken at the Nuclear Regulator

On 19 March 2020, the NRC changed its *modus operandi* in response to COVID-19 and updated its guidance for resident inspectors on 6 April 2020 "to protect the health of inspectors and site personnel, while maintaining oversight that supports reasonable assurance of adequate protection of public health and safety"[209]:

- Deferring of baseline inspections requiring onsite presence such as force-on-force and outage inspections.
- Use of remote means of event response for "uncomplicated plant trips/transients".
- Practice of social distancing when on site and following site specific requirements for COVID-19.
- Remote access of operator information using all available technology (remote connectivity, personal computer, phone, email).
- Visiting each site "approximately once every three business days".[210]

206 - *NIW,* "United States: NRC to Ease Regulatory Burdens During Pandemic", 3 April 2020, see http://www.energyintel.com/pages/eig_article.aspx?DocId=1068608, accessed 28 July 2020.

207 - *The Blade,* "Most work done, but will virus keep Fermi 2 offline much longer?", 15 July 2020.

208 - *Pottstown Mercury,* "Workers 'terrified' at Limerick nuclear plant amid coronavirus", 5 April 2020, see https://www.pottsmerc.com/news/coronavirus/workers-terrified-at-limerick-nuclear-plant-amid-coronavirus/article_934efb34-76a4-11ea-afbe-17495d88f209.html, accessed 27 July 2020.

209 - Christopher G. Miller, "Updated Implementation of Resident Inspector Site Coverage During COVID-19", Director, Division of Reactor Oversight, Office of Nuclear Reactor Regulation, Memorandum to Ho K. Nieh, Director, Office of Nuclear Reactor Regulation, U.S.NRC, 6 April 2020, see https://www.nrc.gov/docs/ML2009/ML20097E538.pdf, accessed 28 July 2020.

210 - Ibidem.

On 28 May 2020, the Director of the Office of Nuclear Reactor Regulation issued a new memorandum on "inspection guidance during transition from COVID-19 mandatory telework".[211] The guidance was "intended to balance the importance of protecting the health and safety of our inspectors and site personnel along with the need to conduct effective oversight that supports NRC's critical safety mission".[212] Many activities have been further delayed with the objective to have them completed within the year. Concerning force-on-force (FOF) security inspections the guidance states that "continued COVID restrictions may necessitate further delays".[213] Early July 2020, nuclear industry representatives made it clear that they want the NRC not to resume but cancel all FOF inspections this year (about 20 reactor sites).[214] The industry made the case that FOF "brings different challenges that lead to a higher possibility of cross-contamination of a critical group of employees".[215] An NRC representative stated that the Atomic Energy Act "specifically highlights that this is a performance-based inspection which cannot be accomplished through paperwork review or tabletop exercises".[216]

A letter signed by 86 organizations to Vice-President Michael R. Pence in late April 2020[217] asked for "urgent actions required to mitigate COVID-19 impacts in nuclear energy industry". The organizations expressed their concern that the NRC "has abdicated its legal responsibility to protect public health and safety during the COVID-19 public health emergency, and to insist upon immediate corrective action". The appeal, sponsored by the Nuclear Information and Resource Service (NIRS), and supported by a long list of well-known national NGOs including Union of Concerned Scientists (UCS), Sierra Club and Friends of the Earth points out:

> As the near disaster resulting from the deferred inspection at the Davis-Besse reactor in 2001-2[218] showed, every single delayed/deferred safety inspection coupled with fatigued and ill workers clearly reduces the overall safety of the 96 [now 95] operating US nuclear power reactors.

The organizations ask for a range of immediate measures including the establishment of an interagency COVID-19 Nuclear Task Force "to develop plans and protective measures for nuclear workers and reactor operations." The NRC brushed off any criticism: "As we've said in several forums, the NRC's authority covers radiological health, not infectious disease health," NRC spokesperson Scott Burnell stated.[219]

211 - Ho K. Nieh, "Inspection Guidance During Transition from COVID-19 Mandatory Telework", Memorandum, Office of Nuclear Reactor Regulation, U.S.NRC, 28 May 2020, see https://www.nrc.gov/docs/ML2014/ML20141L766.pdf, accessed 2 September 2020.

212 - Ibidem.

213 - Ibidem.

214 - Edwin Lyman, Tweet, Union of Concerned Scientists, 9 July 2020, see https://twitter.com/NucSafetyUCS/status/1281216879714095104?s=20.

215 - NRC, "Considerations surrounding security oversight for nuclear power plants in relation to the COVID-19 public health emergency", Transcript of Public Meeting, Undated.

216 - Ibidem.

217 - Nuclear Information and Resource Service, Beyond Nuclear et al., "Letter from 86 Organizations to Vice President Michael R. Pence: Urgent Actions Required to Mitigate COVID-19 Impacts in Nuclear Energy Industry", 22 April 2020, see https://www.nirs.org/wp-content/uploads/2020/04/Nuclear-COVID19-letter_WH-CoV-Task-Force_86-organizations.pdf, accessed 2 September 2020.

218 - A large, pineapple-sized hole was discovered in the reactor vessel head leaving only the liner as barrier. It was later calculated that the hole would have widened to the point where the liner ruptured in another 2 to 11 months of operation. Because Davis-Besse ran 18 months between refueling outages, had the damage been missed during the 2002 outage, it seems likely that a large loss of coolant accident would have occurred. See Mycle Schneider, Georgui Kastchiev, Ed Lymann et al., "Residual Risk—An Account of Events in Nuclear Power Plants Since the Chernobyl Accident in 1986", May 2007, see http://large.stanford.edu/courses/2013/ph240/bechstein1/docs/kastchiev.pdf, accessed 2 September 2020.

219 - *NIW*, "Nuclear Overseers Vary Response to Covid-19", 5 June 2020.

LONGER-TERM IMPLICATIONS

As of mid-2020, the COVID-19 pandemic so far has not led to any interruptions of primary energy or electricity supply in monitored countries. The Council of European Energy Regulatory (CEER) proudly stated:

> No COVID-19 network congestion issues or problem with security of supply have been reported. The EU regulatory framework of liberalised energy markets regulated by independent regulators working for an integrated internal energy market has shown its resilience.[220]

Eurelectric, representing the European electricity industry, at the end of March 2020 published a useful country-by-country overview of impact on the sector and measures taken by Governments and companies.[221] In general, most of the countries have experienced significantly declining power consumption and lower prices. According to one estimate, the five Western European countries France, Germany, Italy, Spain and United Kingdom averaged a drop of 8 percent in power demand over the first half-year 2020, ranging from –9 percent in Germany to –15 percent in France. The analysts expect demand remaining –4 to –8 percent (–10 percent in the U.K.) below 2019 levels[222] Power prices plunged to around €20/MWh in the EU as a whole.

The longer-term impact of low consumption and low prices on the finances of the electricity utilities will be significant.

In **France**, massive outage rescheduling at the 56 nuclear reactors looks likely to extend into the high-consumption winter months 2020-21, and the country will probably need to rely on much more expensive power from other suppliers including from other countries.

Operator EDF plans to shorten the duration of refueling and maintenance outages by up to 2.5 months at 23 reactors to ease some of the effect.[223] Considering the operator's incapacity to respect its outage schedules over the past years (see France Focus), it will be interesting to see how EDF will perform.

Credit-rating agencies were quick to act. On 24 April 2020, Fitch revised EDF's outlook to negative from stable, reflecting "production cuts due to the pandemic" as a key rating driver.[224] Two days later, Moody's did the same, arguing reduced output projections in particular "as a result of confinement and staff protection measures".[225] Standard & Poor's went further and

220 - CEER, "Keeping the lights on saves lives – Energy sector and regulators guarantee energy supply during lockdown", Council of European Energy Regulatory, PR-20-02, 14 April 2020, see https://www.ceer.eu/documents/104400/-/-/9ab3bcce-b191-4414-4e1b-97e6545c24fd, accessed 3 September 2020.

221 - Eurelectric, "Impact of COVID-19 on Customers and Society – Recommendations from the European Power Sector", 31 March 2020, see https://cdn.eurelectric.org/media/4313/impact_of_covid_19_on_customers_and_society-2020-030-0216-01-e-h-E7E407BA.pdf, accessed 2 September 2020.

222 - Andreas Franke and Jonathan Fox, "EU5 Q2 power demand down 12% on year at 367 TWh", *S&P Global Platts Analytics*, 2 July 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/070220-eu5-power-demand-for-q2-down-12-on-year-at-367-twh, accessed 2 September 2020.

223 - Sophie Tetrel, "EDF shortens planned outages at 23 reactors", *Montel*, 3 July 2020.

224 - Fitch, "Fitch Revises EDF's Outlook to Negative; Affirms IDR at 'A–'", 22 April 2020, see https://www.fitchratings.com/research/corporate-finance/fitch-revises-edf-outlook-to-negative-affirms-idr-at-a-22-04-2020, accessed 2 September 2020.

225 - Moody's, "Rating Action: "Moody's changes aoutlook on EDF to negative, affirms ratings", 24 April 2020, see https://www.moodys.com/research/Moodys-changes-outlook-on-EDF-Trading-to-negative-affirms-rating--PR_423223, accessed 3 September 2020.

on 22 June 2020 downgraded EDF by one notch from A– to BBB+ stating that "the prolonged lower nuclear availability reflects greater operational weakness, which will contribute to a significant decline in profitability".[226]

The lower ratings will make the service of the company's debt more expensive. As of mid-2020, EDF's net debt had grown to €42 billion (US$47.5 billion). It lost about €1 billion (US$1.1 billion) to the COVID-19 circumstances and its profit plunged by 56 percent. EDF warned that the construction interruption at the Flamanville EPR "could result in further delays and additional costs".[227]

In **Japan**, the reduction in electricity generation from nuclear power in 2020 due to extended shutdowns coincides with a significant decline in demand and wholesale prices due to the COVID-19 pandemic.[228] As reported by *Reuters*, day-ahead prices on the Japan Electric Power Exchange (JEPX) dropped as low as ¥0.01 (US$c0.01) per kilowatt hour (kWh)—virtually free power— in February 2020. The impact on the finances of the nuclear utilities could be substantial.

CONCLUSION ON NUCLEAR POWER IN THE AGE OF COVID-19

There is no comprehensive information available for any nuclear country concerning identified cases of COVID-19 in the workforce of companies operating nuclear facilities and their supply chain. Some nuclear operators—like EDF in France—have explicitly refused to publish any data. There is no more information available on the situation at the national nuclear regulators and their technical support organizations. It remains entirely unclear to what extent and under what rules staff are being tested or not for COVID-19, and thus it remains uncertain how comprehensive the current knowledge of the impact of the pandemic in the nuclear sector actually is.

Operators and regulators have implemented widespread measures including telework and social distancing. In some cases, regulators stopped physical inspections almost entirely, and carried out site visits only in urgent cases like incidents relevant to safety or security. Remote work raises cyber-security issues and has its limitations. Most of the computers in nuclear facilities and at regulators are not connected to the internet and do not have any outside connection at all (airgap) in order to lower the possibility of hackers entering sensitive information systems or control functions.

There is no doubt that the quality of oversight of operators of their subcontractors has been seriously impacted, as witnessed by numerous workers. Many outages have been delayed or

226 - S&P, "French Utility EDF Downgraded To 'BBB+' On Prolonged Operational Weakness, Lower Output Due To COVID-19; Outlook Stable", 22 June 2020.

227 - 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 2 September 2020.

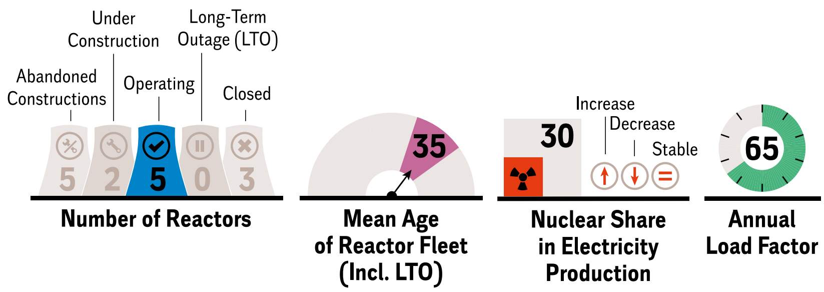
228 - Aaron Sheldrick, "Japan power prices hit zero as coronavirus hammers industrial activity", *Reuters*, 13 May 2020, see https://www.reuters.com/article/us-health-coronavirus-japan-electricity/japan-power-prices-hit-zero-as-coronavirus-hammers-industrial-activity-idUSKBN22P0PA, accessed 19 May 2020.

shortened, which means certain periodical exams and maintenance operations have not been carried out as scheduled.

While it is difficult to assess the degree, it is obvious that the cumulation of these circumstances leads to a shrinking of safety and security margins. It is very surprising under these conditions to see the respective national regulators assuring the public that everything is under control.

FOCUS COUNTRIES

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



The following chapter provides a special focus on nuclear programs in various stages in the Middle East. The section covers six countries in the region, either operating, building or planning for nuclear power plants. In addition, the chapter offers an in-depth assessment of seven countries: China, Finland, France, Japan, South Korea, United Kingdom (U.K.) and the United States (U.S.). They represent about two thirds of the global reactor fleet (60 percent of the units and 67.3 percent of the operating capacity) and five of the world's ten largest nuclear power producers. For other countries' details, see Annex 1.

Unless otherwise noted, data on the numbers of reactors operating and under construction and their capacity (as of mid-2020) and nuclear's share in electricity generation in 2019 are from the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS) online database.[229] Historical maximum figures indicate the year that the nuclear share in the power generation of a given country was the highest since 1986, the year of the Chernobyl disaster. Unless otherwise noted, the load factor figures are from *Nuclear Engineering International* (*NEI*).[230]

MIDDLE EAST FOCUS

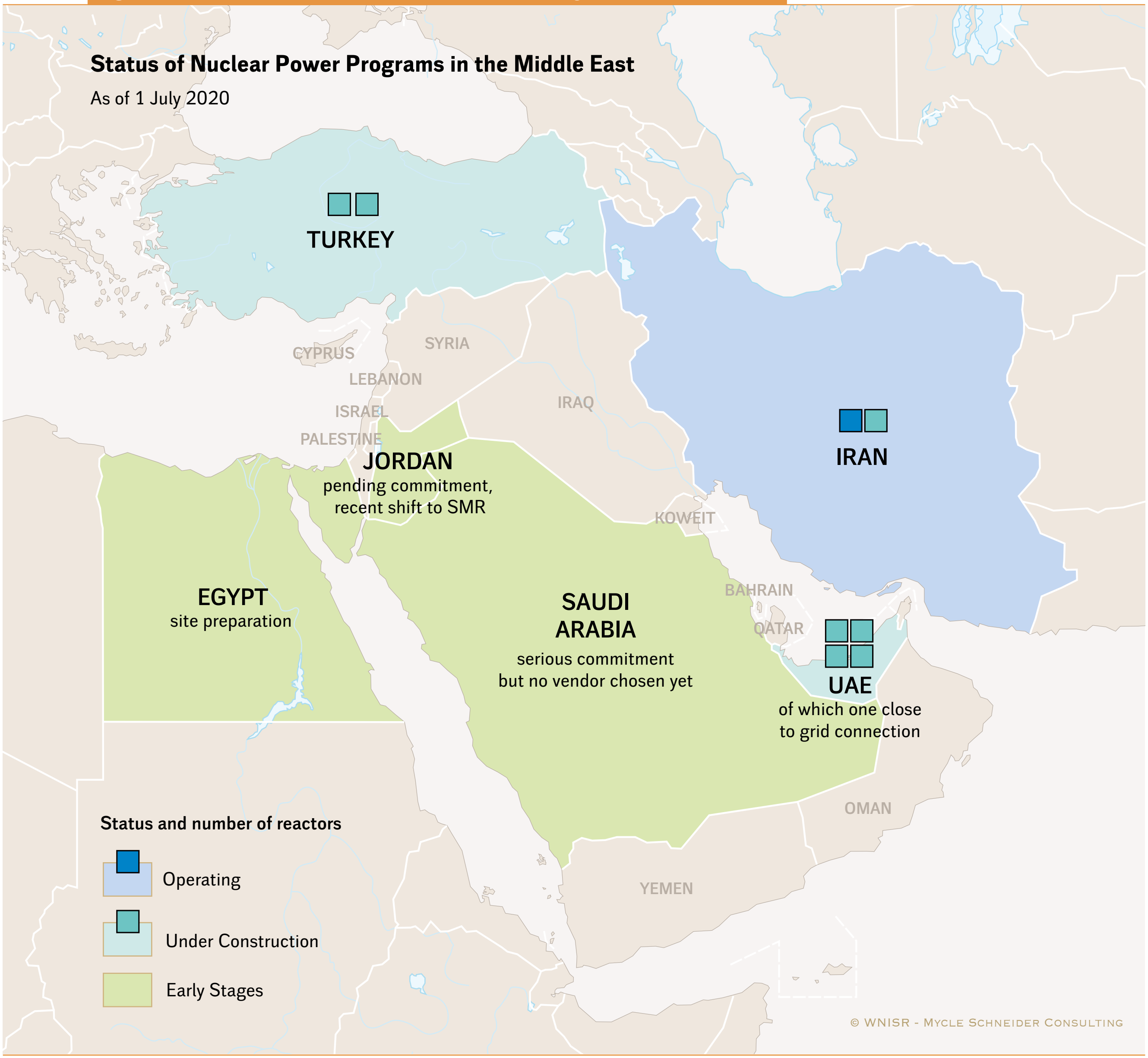
Introduction

In the Middle East, despite decades-long plans to build nuclear power stations, little progress has been achieved. Regional nuclear power projects have stagnated and are facing political and economic uncertainties. Currently, there are six countries in the region with nuclear power ambitions—Iran, United Arab Emirates (UAE), Turkey, Egypt, Saudi Arabia and Jordan (in order of program advancement). As shown in Figure 23, these countries are at very different levels of commitment and progress.

229 - IAEA-PRIS, "Nuclear Share of Electricity Generation in 2019", see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

230 - NEI, "Load factors to end December 2019", June 2020.

Figure 23 · Overview of the Status of Nuclear Power Programs in the Middle East



Source: WNISR, 2020

Interest in nuclear power in Middle Eastern countries stems from various, often unspoken, reasons. Officially communicated rationale to invest in nuclear power in the six countries emphasizes the need to reduce reliance on fossil fuels to generate electricity.[231] Additionally, some countries advocate nuclear power investments as a pathway towards achieving localization of advanced technologies and creating a base of highly skilled workers.[232] On the other hand, investments in nuclear programs across the region, especially in Iran and Saudi

231 - Ali Ahmad, "Energy Transitions in the Gulf: Key Questions on Nuclear Power", January 2018, see https://www.aub.edu.lb/ifi/Pages/publications/books/2017-2018/20180118_energy_transitions_in_the_gulf_key_questions_on_nuclear_power.aspx, accessed 16 April 2020.

232 - Ali Ahmad, Reem Salameh and M.V Ramana, "Localizing Nuclear Capacity? Saudi Arabia and Small Modular Reactors", Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, 2019, see https://www.aub.edu.lb/ifi/Pages/publications/working_papers/2018-2019/20190724-localizing-nuclear-capacity-saudi-arabia-and-small-modular-reactors.aspx, accessed 11 April 2020.

Arabia, are not isolated from the political tensions and their wider security and potential military implications.[233]

Table 3 · Typology of Nuclear Power Programs in the Middle East

Country	Nuclear Capacity	Grid size (Year)	Fuel Arrangements	Fuel Chain Activities
Iran	Operating: 915 MW Under construction: 974 MW	83 GW (2020)	Russia to supply and take back spent fuel under JCPOA terms	Uranium mining, milling, conversion and enrichment; fuel fabrication
UAE	Under construction: 5.4 GW	31 GW (2017)	Diversified fuel supply (six contracts); Long-term spent fuel policy is being developed	None
Turkey	Under construction: 2.2 GW "Committed": 3.6 GW	~91 GW (2019)	Russia to supply and take back spent fuel	None
Egypt	"Committed": 4.8 GW	42 GW (2018)	Russia to supply and take back spent fuel	None
Saudi Arabia	"Committed": 2 GW	89 GW (2017)	Unknown	None
Jordan	Unknown	~5 GW (2017)	Unknown	None

Sources: Various, compiled by WNISR, 2020

Notes: UAE = United Arab Emirates; JCPOA = Joint Comprehensive Plan of Action.

The scope and size of operations of nuclear programs across the region are not uniform. As shown in Table 3, the Iranian nuclear program is the most developed with one operating reactor, one more under construction and investments in uranium mining, conversion and enrichment among other nuclear fuel chain activities. The uranium enrichment component has been the focus of concerted international efforts to limit Iran's nuclear proliferation potential. This had been resolved through the Joint Comprehensive Plan of Action (JCPOA) under which Iran has committed not to reprocess spent nuclear fuel and to send it back to Russia.[234] However, the future of the agreement looks bleak after the Trump administration pulled out of it.

As of mid-2020, Iran's Bushehr-1 was the only operational reactor in the region (see Figure 24). Seven further units are under construction, including the four in the UAE, two in Turkey and one in Iran. Assuming no further delays, the next reactor to be connected to the grid in the region is the Barakah-1 reactor, which is undergoing final tests. When completed and all four units are operational, the plant is projected to provide 25 percent of the country's electricity supply.[235]

Both the Iranian and Emirati nuclear power programs have experienced construction delays (more than 35 years in the case of Bushehr-1). In the case of Iran, delays were mostly due to political reasons, while for the UAE, it was primarily related to the need of further training of local personnel and some unforeseen technical issues.

233 - Anne Neumann et al., "Democratic quality and nuclear power: Reviewing the global determinants for the introduction of nuclear energy in 166 countries", *Energy Research & Social Science*, Volume 63, May 2020, see http://www.sciencedirect.com/science/article/pii/S221462961930667X, accessed 20 April 2020.

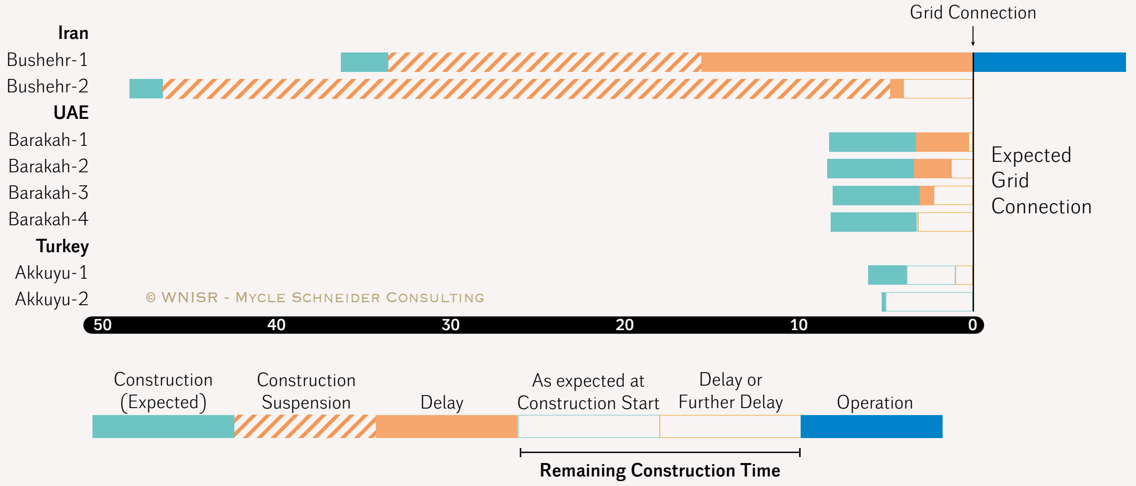
234 - Arms Control Association, "The Joint Comprehensive Plan of Action (JCPOA) at a Glance", May 2018, see https://www.armscontrol.org/factsheets/JCPOA-at-a-glance, accessed 13 April 2020.

235 - *NEI*, "Fuel loading completed at unit 1 of Barakah nuclear power plant in the UAE", 3 March 2020, see https://www.neimagazine.com/news/newsfuel-loading-completed-at-unit-1-of-barakah-nuclear-power-plant-in-the-uae-7805266, accessed 13 April 2020.

Figure 24 · Timelines of Nuclear Power Reactors in the Middle East

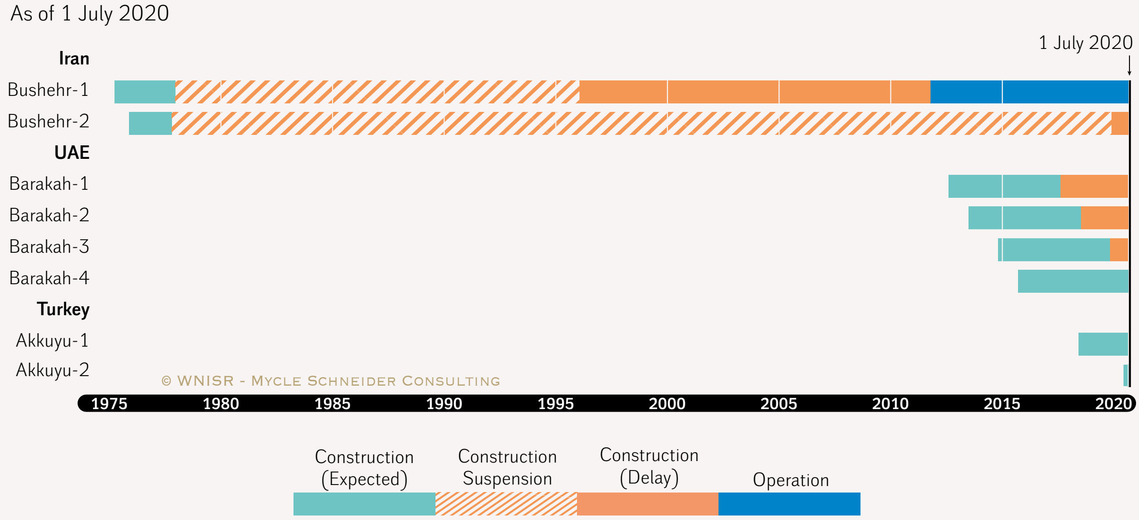
Construction vs. Operation of Nuclear Power Reactors in the Middle East

As of 1 July 2020 - in Years



Timelines of Nuclear Power Reactors in the Middle East

As of 1 July 2020



Sources: Various, compiled by WNISR, 2020

Notes:

Iran: Construction of Bushehr-1 and -2 had originally started in 1975 and 1976. Their supplier, Siemens, suspended construction of both units in 1978 following the beginning of the Iranian Revolution. Construction of Unit 1 restarted in 1996, followed by Unit 2 in 2019. In the absence of an official precise target date for startup of Unit 2, WNISR uses mid-2024 for illustrative purposes.

UAE: Construction of the Barakah reactors was expected to last 5 years each. For illustrative purposes, WNISR noted August 2020 for grid connection of Barakah-1, followed by the other reactors with intervals of one year each.

Turkey: Construction of Akkuyu-1 and -2 was expected to last 5 years, but Unit 1 is already delayed by about one year.

Reactor Suppliers

Russia's Rosatom is the most pro-active reactor provider in the world and the Middle East is no exception, with active projects in Iran and Turkey, and possibly in Egypt (see Table 4). The Korean Electric Power Corporation (KEPCO) currently has the largest number of reactors under construction in the region, with the development of the four-unit Barakah power plant in the UAE. Saudi Arabia has yet to select a nuclear supplier despite entering agreements with several vendors. Besides interest in large reactors, Saudi Arabia and Jordan have also shown interest in Small Modular Reactors (SMRs), although this interest has not yet translated into tangible actions.

Table 4 · Nuclear Technology Suppliers in the Middle East

Large Reactors	
Iran	Rosatom (Russia)
UAE	KEPCO (South Korea)
Turkey	Rosatom (Russia)
Egypt	Rosatom (Russia)
Saudi Arabia	Unknown
Small Modular Reactors	
Saudi Arabia	KAERI (South Korea)
Jordan	Unknown

Sources: Various, compiled by WNISR, 2020.

Notes:

UAE: United Arab Emirates; KEPCO: Korea Electric Power Corporation; KAERI: Korean Atomic Energy Research Institute.

An overview of the latest cost estimates of the regional nuclear power projects and their ownership model is shown in Table 5. These cost estimates do not include, usually significant, indirect costs such as the costs for grid adaptation, of establishing supporting and regulatory institutions, training of personnel, etc. In the six countries examined, and despite different ratios of financing arrangements and ownership models, Governments (on both the recipient and vendor sides) are playing a central role in advancing the nuclear agenda in the region. This is very much in line with the business model of the nuclear industry globally, which is heavily dependent on governmental support and interventions.[236]

The credit rating and debt-to-GDP numbers, also listed in Table 5, offer a glimpse of the economic environments in which the regional nuclear projects are to be established. Egypt and Jordan stand out as the two countries with both low credit-rating score and high debt-to-GDP. Turkey's credit rating is also deep in "junk" territory (highly speculative). The combined effect of such unfavorable economic indicators increases the cost of financing, which will further inflate the cost of the capital-intensive nuclear projects, unless the vendor country offers a financial subsidy, such as loan guarantees or low interest rates.

236 - Nadira Barkatullah and Ali Ahmad, "Current status and emerging trends in financing nuclear power projects", *Energy Strategy Reviews*, 1 December 2017.

Table 5 · Overview of the costs of nuclear power projects in the Middle East and relevant economic indicators

Country	Project Size (GW)	Project Cost Estimate	Ownership Model	Credit Rating Score[237]	Debt-to-GDP
Egypt	4.8	US$29.4 billion	Joint venture	30 (highly speculative)	83%
Iran	2.0	US$10 billion (Bushehr Unit 2 & 3)	Government	NA	32%
Jordan	Unknown	Unknown	Unknown	35 (highly speculative)	94%
Saudi Arabia	Unknown	Unknown	Unknown	76 (upper medium grade)	19%
Turkey	4.8	US$20 billion (Akkuyu)	Build-Own-Operate (BOO)	36 (highly speculative)	29%
UAE	5.6	US$28.2 billion	Joint venture	90 (high grade)	22%

Sources: Various, compiled by WNISR, 2020.

United Arab Emirates

Among the Arab countries with nuclear power ambitions, the UAE's program is by far the most advanced one. The UAE established its nuclear power program in 2009, when it signed a contract with the Korean Electric Power Corp. (KEPCO). The deal initiated the construction of four APR-1400 reactors with a total capacity of 5.6 GW at the Barakah site in Abu Dhabi, the first of which received its operating license in February 2020.[238] In October 2016, KEPCO took an 18 percent equity stake in the Nawah Energy Company that owns the four reactors, with Emirates Nuclear Energy Corporation (ENEC) holding the remaining 82 percent.[239]

At the time of the contract signing in December 2009, ENEC said that "the contract for the construction, commissioning and fuel loads for four units equaled approximately US$20 billion".[240] However, cost estimates later increased to at least US$28.2 billion.[241] Reportedly, financing was primarily supported by the Government of Abu Dhabi; Korean and other financing partners also contributed through equity and loan agreements.[242]

237 - The score is calculated from the ratings of the main rating agencies S&P, Moody's and Fitch. Where available, DBRS Morningstar ratings are also integrated. The maximum score is 100. Trading Economics, "Credit Rating - Countries", 2020, see https://tradingeconomics.com/country-list/rating, accessed 12 May 2020.

238 - WNA, "Barakah nuclear power plant takes a big step forward to delivering UAE's clean energy future", Press Release, 19 February 2020, see https://www.world-nuclear.org/press/press-statements/barakah-nuclear-power-plant-takes-a-big-step-forwa.aspx, accessed 13 April 2020.

239 - *NEI*, "Kepco and Enec set up joint venture for Barakah NPP", 25 October 2016, see http://www.neimagazine.com/news/newskepco-and-enec-set-up-joint-venture-for-barakah-npp-5647366/, accessed 22 April 2018.

240 - ENEC, "UAE Selects Korea Electric Power Corp, as Prime Team as Prime Contractor for Peaceful Nuclear Power", Emirates Nuclear Energy Corporation, 27 December 2009, see https://www.enec.gov.ae/news/uae-selects-korea-electric-power-corp-as-prime-team-as-prime-contractor-fo/, accessed 22 April 2018.

241 - WNISR, 2019.

242 - *NIW*, "Kepco takes 18% of Barakah", 21 October 2016.

In July 2010, a site-preparation license and a limited construction license were granted for the reactors at Barakah,[243] 40 km from the border with Saudi Arabia and 100 km from Qatar. A tentative schedule published in late December 2010, suggested that—with construction starting one unit per year between 2012 and 2015—Barakah-1 would start commercial operation in May 2017 with Unit 2 operating from 2018, Unit 3 starting up in 2019, and Unit 4 following in 2020. However, the project has experienced several delays and is currently projected to start in the second half of 2020. In May 2020, ENEC's CEO Mohamed Al Hammadi stated that the Barakah plant will reach first criticality "within a month or so".[244]

The delays can be linked to the following contributing factors:

- Delays in establishing a domestic workforce that is trained and licensed to operate nuclear reactors safely.[245]
- Cracks or "voids" found in the containment building of Units 2 and 3.[246]
- Precautionary measures in response to South Korean nuclear industry's quality assurance scandal.[247]
- Delays in the commissioning of KEPCO's reactors in South Korea, which are basis for the UAE designs.[248]

In May 2017, ENEC admitted that the startup delay for Unit 1 from 2017 to 2018 was "to ensure sufficient time for international assessments and adherence to nuclear industry safety standards, as well as a reinforcement of operational proficiency for plant personnel."[249] The issue of the delays in achieving an adequate level of personnel training seems to be compounded by the multiplicity of cultures and languages among new personnel.[250] As a recognition of the scale of the ongoing problem, EDF in November 2018 signed an agreement with ENEC to provide services to support "operating and maintaining" the plant.[251]

243 - *Arabian Business*, "ENEC Welcomes Regulator's License Approval", 11 July 2010, see http://www.arabianbusiness.com/enec-welcomes-regulator-s-licence-approvals-306150.html, accessed 22 April 2018.

244 - *WNN*, "ENEC CEO: Barakah plant to start up 'very soon'", 7 May 2020, see https://world-nuclear-news.org/Articles/ENEC-CEO-Barakah-to-start-up-very-soon, accessed 14 May 2020.

245 - Jane Chung and Geert De Clercq, "UAE delays launch of first nuclear power reactor", *Reuters*, 4 May 2017, see https://www.reuters.com/article/us-kepco-emirates-nuclearpower-exclusive/exclusive-uae-delays-launch-of-first-nuclear-power-reactor-idUSKBN1801ZD, accessed 22 April 2018.

246 - Choi Ha-yan, "KEPCO undergoes repairs for cracks in nuclear reactor containment buildings in UAE", *The Hankyoreh*, 17 October 2018, see http://english.hani.co.kr/arti/english_edition/e_business/866228.html, accessed 19 May 2019.

247 - Max. S Kim, "How greed and corruption blew up South Korea's nuclear industry", *MIT Technology Review*, 22 April 2019, see https://www.technologyreview.com/2019/04/22/136020/how-greed-and-corruption-blew-up-south-koreas-nuclear-industry/, accessed 13 May 2020.

248 - Anthony McAuley, "UAE nuclear project enters critical phase", *The National*, 7 July 2015, see https://www.thenational.ae/business/uae-nuclear-project-enters-critical-phase-1.26641, accessed 13 May 2020.

249 - ENEC, "ENEC Announces Completion of Initial Construction Work for Unit 1 of Barakah Nuclear Energy Plant & Progress Update Towards Safety-led Operations", Press Release, 5 May 2017, see https://www.enec.gov.ae/news/latest-news/enec-announces-completion-of-initial-construction-work-barakah-unit-1-progress-update/, accessed 18 July 2020.

250 - Stephanie Cook, "The Challenge of Barakah's Multicultural Workforce", *NIW*, 23 March 2018.

251 - EDF and Nawah Energy Company, "EDF and Nawah Energy Company sign operations and maintenance assistance agreement for Barakah Nuclear Energy Plant, United Arab Emirates", Press Release, 22 November 2018, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-and-nawah-energy-company-sign-operations-and-maintenance-assistance-agreement-for-barakah-nuclear-energy-plant-united-arab-emirates, accessed 9 April 2019.

Worker safety has also been a challenge. According to one South Korean media report, there have been a number of serious accidents at the construction site, resulting in deaths of workers and KEPCO's contractors were found to have "largely failed to ensure worker safety".[252]

The problem of defects in the containment buildings was similar to a problem that had been experienced in the 1990s at the Hanbit reactor in South Korea, where holes large enough for a small child were revealed.[253] The discovery of such defects in Barakah raised concerns on safety and project management. The safety concern is because the containment building is a crucial barrier to stop potentially radioactive emissions escaping in the event of an accident. The latter concern is because construction has not gone smoothly and raises the question of possible other overlooked issues.

Further difficulties have emerged with the APR-1400 design, raising questions about the reliability of the pilot-operated safety relief valves (POSRV). These are designed to protect the pressurizers against overpressure and have been seen to be a problem for the design since 2016 when it inadvertently opened, during start-up of Shin-Kori-3 in South Korea. Then, possibly during testing, in November 2017 the same problem occurred at Barakah-1, and the regulator concluded that the valve did not meet its safety acceptance criteria.[254]

Nevertheless, the Barakah project has been moving toward completion. In December 2019, it was reported, based on ENEC's estimates, that the overall construction of the four units was at more than 93 percent. Besides Unit 1, the construction of which is now completed, Units 2, 3 and 4 were reported at more than 95, 91 and 82 percent complete, respectively.[255]

The first group of operators at the plant received their certification in July 2019 after a three-year training program.[256] In September 2019, at the 24th World Energy Congress in Abu Dhabi, Barakah One Company and KEPCO signed an agreement to explore opportunities to offer the "Barakah model" to foreign markets.[257]

In February 2020, the first unit at Barakah received its operating license from the UAE's Federal Authority for Nuclear Regulation (FANR), authorizing 60 years of operation. In March 2020, fuel loading was completed in Unit 1, making UAE officially the first Arab country with a nuclear power plant. Officials said that systems would be tested over the following few months, with power production to begin once testing is completed. Grid connection had been expected to take place before mid-2020, which did not happen.[258]

252 - Lee Hyo-sik, "KEPCO hit by safety lapses at UAE nuke plant site", *The Korean Times*, 22 February 2017, see http://www.koreatimes.co.kr/www/biz/2017/02/367_224498.html, accessed 22 April 2018.

253 - Choi Ha-yan, "Controversy over Barakah power plant construction fiasco continues", *Hankyoreh*, 18 December 2018, see http://english.hani.co.kr/arti/english_edition/e_international/874896.html, accessed 9 April 2019.

254 - Stephanie Cook, "Shared POSRV Nightmares for KHNP and Enec", *NIW*, 15 March 2019.

255 - *Technical Review Middle East*, "ENEC highlights nuclear energy and Barakah plant progress at public forum", 2 December 2019, see http://www.technicalreviewmiddleeast.com/power-a-water/power-generation/enec-highlights-nuclear-energy-and-barakah-plant-progress-at-public-forum, accessed 13 April 2020.

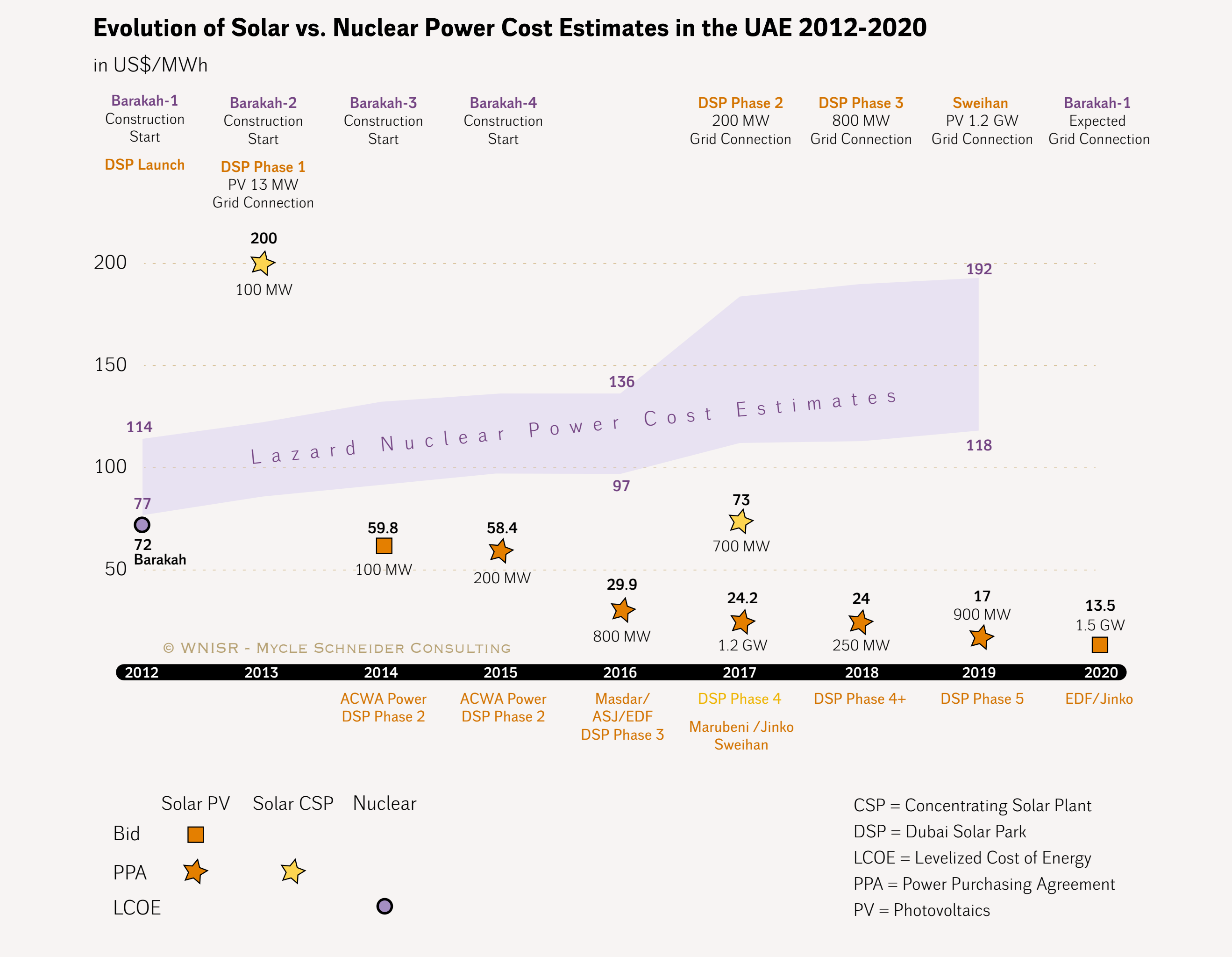
256 - *WNN*, "First Barakah operators receive regulatory certification", 8 July 2019, see https://world-nuclear-news.org/Articles/First-Barakah-operators-receive-regulatory-certifi, accessed 13 April 2020.

257 - *GCR*, "Korea and UAE sign nuclear know-how export deal", *Global Construction Review*, 12 September 2019, see http://www.globalconstructionreview.com/news/korea-and-uae-sign-nuclear-know-how-export-deal/, accessed 13 April 2020.

258 - Barakah-1 was finally connected to the grid on 19 August 2020. C.f. WNISR, "Barakah, UAE: Grid Connection of First Commercial Reactor in the Arab World", 21 August 2020, see https://www.worldnuclearreport.org/Barakah-UAE-Grid-Connection-of-First-Commercial-Reactor-in-the-Arab-World.html, accessed 8 September 2020.

The delays in the construction of the Barakah project have led to a significant increase in the construction and financing costs through, primarily, extended interest payments and deferred revenues. As shown in Figure 25, these delays occur while solar power has made huge leaps in the UAE towards cost effectiveness. The latest solar-photovoltaics (PV) bid in the fifth phase of the Dubai solar park reached US$1.7 c/kWh in 2019, less than a quarter of the Barakah's projected levelized cost of energy (LCOE), estimated at US$$_{2012}$ 7.2 cents per kWh.[259] Even concentrated solar reached prices similar to the expected nuclear levels as early as 2017 in the fourth phase of the Dubai solar park.

Figure 25 · Evolution of Solar PV and CSP Prices in the UAE During the Construction of the Barakah Project



Sources: Multiple, compiled by WNISR, 2020.

Note: All numbers in nominal US dollars.

Since 2013, the UAE has been home to record-breaking prices of solar energy projects. Since then, not only solar power became more cost competitive vis-à-vis nuclear, it has been experiencing a diverging trend with dramatic cost reductions, while the cost of nuclear electricity has increased in what can be described as "negative learning".

259 - WNISR estimate (based on latest project cost of US$28.2 billion at 5 percent discount rate)

The Barakah delays are in line with the global trend of lengthy lead and construction times of nuclear power plants. They show that even in the UAE, with readily available financing and access to arguably the best consultants and technical experts in the world, problems and delays are bound to happen with nuclear projects.

Saudi Arabia

Saudi Arabia's interest in acquiring nuclear power started to take shape in late 2006, initially envisaged as part of a joint GCC (Gulf Cooperation Council) effort.[260] The King Abdullah City for Atomic and Renewable Energy (KA-CARE), which has been mandated with overseeing the development of the kingdom's nuclear power program, was set up in 2010. In June 2011, KA-CARE announced plans to build 16 nuclear power reactors, with a total capacity target of 17.6 GW. The first two reactors were planned to be online ten years later and then two more per year until 2030. However, these ambitious plans are no longer endorsed by the Saudi leadership.

In March 2018, the Government approved a national nuclear program, with reports suggesting contracts for the construction of two reactors by the end of 2018,[261] and planned commissioning in 2027.[262] These contracts were not signed. However, Energy Minister Khalid al-Falih said in January 2019 that his Government still planned to build two reactors in the next decade and then expand the program once these were in operation.[263] The kingdom also confirmed that it had short-listed five nuclear technology vendors: Westinghouse, Rosatom, KEPCO, EDF/Orano, and China National Nuclear Corporation (CNNC).[264] Amongst the bidders, KEPCO is thought to be in a strong position, given its experience in the UAE.[265]

In mid-2018, the IAEA undertook an Integrated Nuclear Infrastructure Review (INIR) in the country. Mikhail Chudakov, IAEA Deputy Director General, stated on the completion of the review that Saudi Arabia had established a legislative framework to support the next stage of nuclear development.[266]

Reuters reported in April 2019 that a full tender would be launched in 2020.[267] Importing equipment from the United States will require the signing of a Nuclear Cooperation

260 - Hassan M. Fattah, "Arab Nations Plan to Start Joint Nuclear Energy Program", *The New York Times*, 11 December 2006, see https://www.nytimes.com/2006/12/11/world/middleeast/11nuke.html, accessed 10 April 2020.

261 - *NEI*, "Saudi Arabia approves national nuclear programme", 19 March 2018, see http://www.neimagazine.com/news/newssaudi-arabia-approves-national-nuclear-programme-6087593/, accessed 25 April 2018.

262 - *NEI*, "Saudi Arabia to prequalify NPP bids by May", 18 January 2018, see http://www.neimagazine.com/news/newssaudi-arabia-to-prequalify-npp-bids-by-may-6029868/, accessed 25 April 2018.

263 - *Saudi Gazette*, "Saudi Arabia to use N-energy for electricity production, asserts Al-Falih", 16 January 2019, see http://saudigazette.com.sa/article/557047/SAUDI-ARABIA/Saudi-Arabia-to-use-N-energy-for-electricity-production-asserts-Al-Falih, accessed 14 April 2019.

264 - Noura Mansouri, "Commentary: The Saudi Nuclear Energy Project", King Abdullah Petroleum Studies and Research Center, March 2020, see https://www.kapsarc.org/research/publications/the-saudi-nuclear-energy-project/, accessed 10 April 2020.

265 - Phil Chaffee, "Ka-Care Hopes to Choose from Five Bids by Year's End", *NIW*, 19 January 2018.

266 - IAEA, "IAEA Delivers Report on Nuclear Power Infrastructure Development to Saudi Arabia", 25 January 2019, see https://www.iaea.org/newscenter/news/iaea-delivers-report-on-nuclear-power-infrastructure-development-to-saudi-arabia, accessed 16 June 2019.

267 - Sylvia Westall, Rania El Gamal and Stephen Kalin, "Saudi plans to invite bids for nuclear power project in 2020: sources", *Reuters*, 4 April 2019, see https://uk.reuters.com/article/us-saudi-nuclear/saudi-plans-to-invite-bids-for-nuclear-power-project-in-2020-sources-idUKKCN1RG1LL, accessed 9 April 2019.

Agreement (123 Agreement). Within the United States, there is increasing pressure to include a requirement to forego uranium enrichment and spent fuel reprocessing, which goes against previous Saudi statements about their desire to control the fuel system.[268] Despite this, *Reuters* reported in March 2019 that U.S. Energy Secretary Rick Perry had approved six secret authorizations by companies to sell nuclear power technology. Perry's approvals, known as Part 810 authorizations, allow companies to do preliminary work on nuclear power ahead of any deal.[269] Perry confirmed in October 2019 that talks were ongoing regarding U.S. support for the Saudi nuclear program and potential signing of a 123 agreement.[270]

Concerns have been raised about the connection the Saudi leadership has expressed between the civil nuclear program and the desire to acquire nuclear weapons. In March 2018, Prince Mohammed bin Salman (MBS) told *CBS News*, "Saudi Arabia does not want to acquire any nuclear bomb, but without a doubt if Iran developed a nuclear bomb, we will follow suit as soon as possible."[271] In May 2020, *Bloomberg* reported that Saudi Arabia is continuing the construction of a research reactor without IAEA monitoring, which is a critical issue as the reactor design-information verification has to be conducted while the reactor is being commissioned.[272]

In September 2019, Saudi Arabia's energy minister said that the kingdom is "proceeding cautiously" with plans for two nuclear reactors and added that the kingdom still wants to go ahead with a full fuel chain nuclear program, including production and enrichment of uranium for nuclear fuel.[273] According to Saudi estimates, the kingdom has recoverable domestic resources of around 60,000 tons of uranium ore.[274]

Alexander Voronkov, Rosatom's vice-president, revealed in October 2019 that his country is cooperating with Saudi Arabia and implementing a joint road map for building SMRs. Additionally, he alluded to Rosatom's proposal to support the kingdom in its nuclear fuel chain activities, including training of Saudi personnel.[275] Besides government talks, Rosatom also organized several workshops in an attempt to build networks and relationships with Saudi companies.[276]

268 - Timothy Gardner, "U.S. Senate proposal would block Saudi path to atomic weapon in nuclear deal", *Reuters*, 13 February 2019, see https://www.reuters.com/article/us-usa-nuclear-saudi/u-s-senate-proposal-would-block-saudi-path-to-atomic-weapon-in-nuclear-deal-idUSKCN1Q12UT, accessed 9 April 2019.

269 - Timothy Gardner, "U.S. approved secret nuclear power work for Saudi Arabia", *Reuters*, 27 March 2019, see https://www.reuters.com/article/us-usa-saudi-nuclear-idUSKCN1R82MG, accessed 4 May 2019.

270 - *MEED*, "US confirms nuclear energy talks with Saudi Arabia", *Power Technology*, 30 October 2019, see https://www.power-technology.com/comment/us-confirms-nuclear-energy-talks-with-saudi-arabia/, accessed 10 April 2020.

271 - Aileen Murphy, M.V. Ramana, "The Trump administration is eager to sell nuclear reactors to Saudi Arabia. But why?", *Bulletin of the Atomic Scientists*, 16 April 2019, see https://thebulletin.org/2019/04/the-trump-administration-is-eager-to-sell-nuclear-reactors-to-saudi-arabia-but-why/, accessed 4 May 2019.

272 - Jonathan Tirone, "Saudi Atomic Reactor Progresses With Inspectors Still Frozen Out", *Bloomberg*, 21 May 2020, see https://www.bloomberg.com/news/articles/2020-05-21/saudi-atomic-reactor-progresses-with-inspectors-still-frozen-out, accessed 21 May 2020.

273 - Rania El Gamal and Alexander Cornwell, "Saudi Arabia flags plan to enrich uranium as U.S. seeks nuclear pact", *Reuters*, 9 September 2019, see https://www.reuters.com/article/us-energy-wec-saudi-nuclearpower/saudi-arabia-wants-to-enrich-uranium-for-nuclear-power-minister-idUSKCN1VU168, accessed 10 April 2020.

274 - Sylvia Westall, "Saudi Arabia to extract uranium for 'self-sufficient' nuclear program", *Reuters*, 30 October 2017, see https://www.reuters.com/article/us-saudi-nuclear-idUSKBN1CZ1ON, accessed 10 April 2020.

275 - Alzaid Saleh, "نائب رئيس «روساتوم»: نتعاون مع السعودية لبناء مفاعلات نووية صغيرة", الشرق الأوسط, 14 October 2019 (in Arabic), see https://bit.ly/3fFezEM, accessed 10 April 2020.

276 - Asharq AL-awsat, "«روساتوم» الروسية تنظم ورشة بجدة حول التقنيات النووية والتعاون مع الموردين السعوديين", 28 November 2019 (in Arabic), see https://bit.ly/2ODIXUg, accessed 10 April 2020.

Small Modular Reactors (SMRs)

Besides large reactors, Saudi Arabia is also exploring the option of SMRs. In March 2015, KA-CARE and the Korea Atomic Energy Research Institute (KAERI) signed a Memorandum of Understanding (MoU) to study the feasibility of constructing two SMART reactors (System-integrated Modular Advanced Reactors) in the kingdom, with the cost of building the first reactor estimated at US$1 billion.[277] The agreement also mentioned that the two countries would cooperate on the commercialization and promotion of SMART reactors to other countries.

The progress of the collaboration between Saudi Arabia and South Korea on the SMART venture has been slow. Five years after the initial agreement, a pre-project engineering contract was signed between KA-CARE and South Korea's Ministry of Science and Technology in January 2020.[278] The agreement formalized the establishment of a joint entity to undertake activities related to the licensing and development of business models and infrastructure of the SMART reactor in Saudi Arabia.

Similarly, in March 2017, a cooperation agreement was signed with China Nuclear Engineering Group Corporation (CNEC) on the development of High-Temperature Gas-cooled Reactors (HTGR).[279] So far, these collaborations have not progressed beyond the signing of MoUs and cooperation agreements.

In its 2016 "Vision 2030" document, Saudi Arabia's leadership emphasized the role and importance of localizing energy supply chains. The strategy recognizes localization as pillar of a new and more diversified economy. In late 2016, the kingdom released the "National Transformation Program 2020 (NTP2020)". On the nuclear energy issue, the plan gave specific attention to SMRs, stating targets of nuclear localization as strategic objectives. These targets can be summarized as follows:

- Develop needed qualitative human capabilities for atomic and renewable energy sector;
- Localization of SMRs on the basis of SMART technology;
- Localization of uranium production.

Since the release of the roadmap, little progress has been achieved. The nuclear localization capacity vis-à-vis renewables in Saudi Arabia has been recently examined by three independent experts who concluded that "when it comes to nuclear power, the kingdom presents low technical capabilities, with moderate political support."[280] On the other hand, the report details how the scope, speed and potential of Saudi Arabia's investments in renewable energy

277 - *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.

278 - *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.

279 - *NEI*, "Saudi Arabia looks to China and Korea for nuclear assistance", 20 March 2017, see http://www.neimagazine.com/news/newssaudi-arabia-looks-to-china-and-korea-for-nuclear-assistance-5767240/, accessed 25 April 2018.

280 - Ali Ahmad, Reem Salameh and M. V. Ramana, "Localizing Nuclear Capacity? Saudi Arabia and Small Modular Reactors", Working Paper #51, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, July 2019, see https://www.aub.edu.lb/ifi/Documents/publications/working_papers/2018-2019/20190708_localising_nuclear_capacity_KSA.pdf, accessed 29 June 2019.

value chain seem to surpass that of nuclear energy. For example, in March 2019, the kingdom launched the second phase of its renewable energy program worth around US$1.5 billion.[281]

Unlike nuclear activities that have high decision-making centrality, investments in renewables in the kingdom are done on both Government and private sector levels. On the Government level, some serious investment efforts have been made to localize manufacturing solar PV panels. In February 2019, LONGi, a Chinese solar technology manufacturing giant, revealed that it is planning to open a US$2 billion solar panel production plant in Saudi Arabia.[282]

On the private sector level, Saudi-based companies, including ACWA Power—a regional heavy weight energy company—are now involved in several flagship projects inside and outside the kingdom. For example, ACWA Power is the developer of the 950 MW hybrid project (700 MW Concentrated Solar Power and 250 MW Photovoltaics) of the fourth phase of the Mohammed Bin Rashid Al Maktoum Solar Park, the largest single-site of concentrated solar power plant in the world.[283]

Turkey

In Turkey, three separate projects have been in the planning stage for many years, with three different reactor designs and three different financing schemes. However, as of mid-2020, construction only began on the first of these projects.

Akkuyu

Over four decades after it was first proposed, construction of a nuclear power plant at Akkuyu in the province of Mersin on Turkey's Mediterranean coast started in April 2018.[284] The power plant is to be implemented by Rosatom of Russia under a Build-Own-Operate (BOO) model. An agreement was signed in May 2010 for four VVER1200 reactors (Generation III+), with construction originally expected to start in 2015. Only two months prior to the official construction start, Rosatom's Turkish partners, who were to hold 49 percent of the shares, quit.[285] However, Rosatom has stated that it would be able to complete the project even if it is unable to attract local investors.[286] In April 2019, Rosatom stated that it was in talks with both

281 - *Asharq al-Awsat*, "Saudi Arabia Announces 7 Renewable Energy Projects Worth $1.5 Bn", 12 March 2019, see https://english.aawsat.com/home/article/1630351/saudi-arabia-announces-7-renewable-energy-projects-worth-15-bn, accessed 14 May 2020.

282 - Jason Deign, "Saudi Arabia Looks to China for Solar as Power Politics Shift", *Greentech Media*, 2 May 2019, see https://www.greentechmedia.com/articles/read/saudi-looks-to-china-for-solar-as-power-politics-shift, accessed 11 April 2020.

283 - ACWA POWER, "Noor Energy 1", 2020, see https://www.acwapower.com/en/projects/noor-energy-1/, accessed 14 May 2020.

284 - Tuvan Gumrukeu and Orhan Coskun, "Turkey grants Rosatom construction license for first unit of Akkuyu nuclear plant", *Reuters*, 2 April 2018, see https://www.reuters.com/article/us-turkey-russia-nuclearpower/turkey-grants-rosatom-construction-license-for-first-unit-of-akkuyu-nuclear-plant-idUSKCN1H91OY, accessed 22 May 2018.

285 - *AFP*, "Un consortium turc se retire du projet de la centrale nucléaire d'Akkuyu", *Agence France Presse*, 6 February 2018 (in French).

286 - *Reuters*, "Russia capable of building Akkuyu plant without partners: Minister", as published in *Hurriyet Daily News*, 6 April 2018, see http://www.hurriyetdailynews.com/russia-is-able-to-complete-akkuyu-nuclear-power-plant-construction-russian-minister-129886, accessed 6 April 2018.

state-run and private Turkish companies, seeking to sell 49 percent of the project.[287] So far, however, there is no evidence that such efforts were successful.

The financing of the project is supported by a 15-year Power Purchase Agreement (PPA), which includes 70 percent of the electricity produced from Units 1 and 2 and 30 percent of Units 3 and 4. Therefore 50 percent of the total power from the station is to be sold at a guaranteed price for the first 15 years, with the rest to be sold on the market. Currency fluctuation, and the fall in the value of the Turkish lira, makes the price guarantees in dollars (US$123.50/MWh) problematic.[288]

In October 2013, the Akkuyu project was announced to become operational by mid-2020.289 However, numerous delays have occurred (see previous editions of the WNISR), and by the time construction started in April 2018, first electricity was expected to be generated in 2023 (the 100th anniversary of the founding of the modern state of Turkey), with all four units to be operational by 2025.[290]

In March 2019, the project management announced that it had finished the concreting of the basemat for the nuclear island for the first unit and that it was now expected that Unit 1 would be physically completed in 2023, with generation coming at a later date.[291] In September 2019, Rosatom announced that the license for Unit 2 had been granted in the previous month, and that it was preparing to install the first steel equipment on Unit 1 in the autumn.[292] Russia's largest bank, Sberbank, had announced in August 2019 that it would provide a US$400 million loan to Rosatom for the plant's construction.[293]

In May 2019, it was reported that construction of Unit 1 had been "held up" due to the discovery of cracks in the foundations, and after further cracks were discovered in the re-laid concrete, a larger section of the foundations had to be redone.[294]As for Akkuyu's Unit 2, Turkish media sources in late June 2020 reported that construction has started that same month.[295] Strangely, as of early July 2020, Rosatom had not communicated about the event. It is only in late July 2020 that the company confirmed and provided a date of April 2020 for first concrete pouring.[296]

287 - *Ahval*, "Russia's Rosatom in talks to sell 49 pct stake in Akkuyu nuclear plant", 15 April 2019, see https://ahvalnews.com/akkuyu/russias-rosatom-talks-sell-49-pct-stake-akkuyu-nuclear-plant, accessed 18 April 2019.

288 - Phil Chaffee, "New Build, Revised 2023 Milestone for Akkuyu", *NIW*, 29 March 2019.

289 - Orhan Coskun and Humeyra Pamuk, "Turkey's first nuclear plant facing further delays - sources", *Reuters*, 7 February 2014, see https://uk.reuters.com/article/uk-turkey-nuclear-delay/turkeys-first-nuclear-plant-facing-further-delays-sources-idUKBREA160P220140207, accessed 22 April 2018.

290 - *NEI*, "Construction of Turkey's Akkuyu NPP begins", 4 April 2018, see http://www.neimagazine.com/news/newsconstruction-of-turkeys-akkuyu-npp-begins-6102914/, accessed 22 April 2018.

291 - Phil Chaffee, "New Build, Revised 2023 Milestone for Akkuyu", *NIW*, 29 March 2019.

292 - Geert De Clercq, "Rosatom wins licence to build second nuclear reactor in Turkey -deputy CEO", *Reuters*, 6 September 2019, see https://www.reuters.com/article/rosatom-nuclearpower-turkey-idUSL5N25X40O, accessed 14 April 2020.

293 - David Dalton, "Russia's Sberbank To Provide $400 Million Loan For Turkish Reactors", *NucNet*, 21 August 2019, see https://www.nucnet.org/news/russia-s-sberbank-to-provide-usd400-million-loan-8-3-2019, accessed 14 April 2020.

294 - *Ahval*, "Cracks discovered during construction of Turkey's first nuclear plant", 6 May 2019, see https://ahvalnews.com/akkuyu/cracks-discovered-during-construction-turkeys-first-nuclear-plant, accessed 11 June 2019.

295 - *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.

296 - *NIW*, "Turkey: Rosatom Confirms Akkuyu-2's April First Concrete Pour", 24 July 2020.

Sinop

Sinop is on Turkey's northern coast and was planned to host a 4.4 GW power plant of four units of the ATMEA reactor-design. If completed, these would have been the first reactors of this design, jointly developed by Japanese Mitsubishi and French AREVA (now Framatome, again).[297] In April 2015, Turkish President Erdogan approved parliament's ratification of the intergovernmental agreement with Japan.[298]

However, after three and a half years of unsuccessful attempts to renegotiate the deal (see previous editions of the WNISR), in December 2018, the Japanese newspaper *Nikkei* reported that Mitsubishi Heavy Industries (MHI) had withdrawn, finally ending the project.[299] Energy Minister Fatih Dönmez stated that the time schedule and pricing of Sinop fell short of the ministry's expectations after the results of feasibility studies, carried out by MHI. "We agreed with the Japanese side to not continue our cooperation regarding this matter."[300]

Reportedly, while there is neither an apparent nuclear builder nor an officially selected design, the Turkish authorities have moved forward with an administrative Environmental Impact Assessment (EIA).[301] The company that has submitted the EIA application on 30 March 2020 is Assystem ENVY Energy and Environmental Investment on behalf of EUAS International ICC Sinop Nuclear Power Plant, Jersey Islands, Turkey Central Branch. The EIA report strangely mentions the Flamanville-3 EPR reactor in France, currently under construction, as "reference reactor", while the original EIA from 2018 was based on the AREVA-Mitsubishi ATMEA design, which has never gone beyond the design phase anywhere. Neither of the French companies EDF or subsidiary Framatome (former AREVA NP) have communicated on the issue.

İğneada

In October 2015, the Turkish Government suggested it was aiming to build a third nuclear power plant, at the İğneada site. The most likely constructors would be Westinghouse and the Chinese State Nuclear Power Technology Corporation (SNPTC). Chinese companies have been said to be "aggressively" pursuing the contract, reportedly worth an estimated US$22-25 billion. In September 2016, China and Turkey signed a nuclear co-operation agreement similar to the mechanism used to develop the country's other nuclear projects.

However, the financial collapse of Westinghouse effectively buried the project.

297 - *WNN*, "Turkish utility eyes large stake in Sinop project", 12 May 2015, see http://www.world-nuclear-news.org/C-Turkish-utility-eyes-large-stake-in-Sinop-project-12051501.html, accessed 22 April 2018.

298 - *WNN*, "Ground broken for Turkey's first nuclear power plant", 15 April 2015, see http://www.world-nuclear-news.org/NN-Ground-broken-for-Turkeys-first-nuclear-power-plant-1541501.html, accessed 22 April 2018.

299 - Matsukubo Hijime, "Mitsubishi Heavy Industries withdraws from the NPP project in Sinop, Turkey ~NPP makers need to switch to realistic track in the age of decommissioning~", Citizens' Nuclear Information Center, 30 January 2019, see http://www.cnic.jp/english/?p=4271, accessed 11 June 2019.

300 - *NEI*, "Turkey looks to cancel Japan Sinop project", Nuclear Engineering International, 27 January 2020, see https://www.neimagazine.com/news/newsturkey-looks-to-cancel-japan-sinop-project-7653758/, accessed 13 June 2020.

301 - *WNN*, "Turkish utility to cooperate with Rolls-Royce in SMRs", 20 March 2020, see https://world-nuclear-news.org/Articles/Turkish-utility-to-cooperate-with-Rolls-Royce-in-S, accessed 14 April 2020.

Small Modular Reactors

In addition to the existing planned nuclear projects, Turkey is exploring the potential for SMRs. In March 2020, the U.K.'s Rolls-Royce and Turkey's state-owned EÜAS International ICC signed an agreement to study the potential for small modular reactors from a technical, licensing, commercial and investment perspective and the possibility of joint production of SMRs in Turkey and globally.[302]

Public Attitudes and Social Implications

The spread of an anti-nuclear sentiment within the Turkish public dates back to the 1970s and is rooted in the country's well-established environmental justice movements.[303] Fueled by the fear of a repetition of disasters like Chernobyl or Fukushima, social mobilization against nuclear power plants has been taking place in big cities and near the selected nuclear sites, protesting safety threats, legality of waste disposal, high costs and administrative shortcomings among other issues.[304]

Beside these well-known challenges that transcend the case of Turkey, the Akkuyu project is also generating some serious social challenges, particularly on the level of the local population living nearby the construction site. Although the construction of Akkuyu started only two years ago, the nuclear power plant constitutes already a problem in the eyes of the local population. According to recent field research, the Akkuyu construction site and its workers are negatively impacting the safety, security and public health of local villagers as well as the state of the environment.[305] Among the reported effects are the sharp increase in population in a very short period of time due to the influx of workers and subcontractors, leading to increased events of harassment against women, bullying and theft. Investigating the root cause of these issues, the research found that the Akkuyu construction workers themselves are not provided with decent living conditions, where their social and psychological needs are met.

Since it was licensed in 1976, the choice of the Akkuyu site has been criticized for its seismic risks, which have received more attention in the wake of the Fukushima disaster.[306] Since then, various public surveys have been conducted to assess the public's sentiment towards Turkey's nuclear power plans (see Figure 26). According to the latest survey in 2018, two thirds of the Turkish public do not support their country's efforts to build nuclear power plants, stating that "it is clearly risky, nuclear power plants should never be built.".[307] The survey also showed that the anti-nuclear sentiment is across all political affiliations. Even within the AKP, the ruling

302 - *WNN*, "Turkish Utility to Cooperate with Rolls-Royce in SMRs", 20 March 2020.

303 - Pinar Temocin, "Framing Opposition to Nuclear Power: The Case of Akkuyu in Southeast Turkey", Institute for Peace and Unification Studies, Seoul National University, *Asian Journal of Peacebuilding*, November 2018.

304 - Mustafa Kibaroglu, "Turkey's Quest for Peaceful Nuclear Power", *The Nonproliferation Review*, September 1997; and Mustafa Balat, "Energy and Nuclear Power Planning Study for Turkey", *Energy Exploration & Exploitation*, 1 February 2006.

305 - Pınar Demircan, "Akkuyu Nuclear Power Plant is already a problem", *Yeşil Gazete*, 24 October 2019, see https://yesilgazete.org/blog/2019/10/24/akkuyu-nuclear-power-plant-is-already-a-problem/, accessed 30 May 2020.

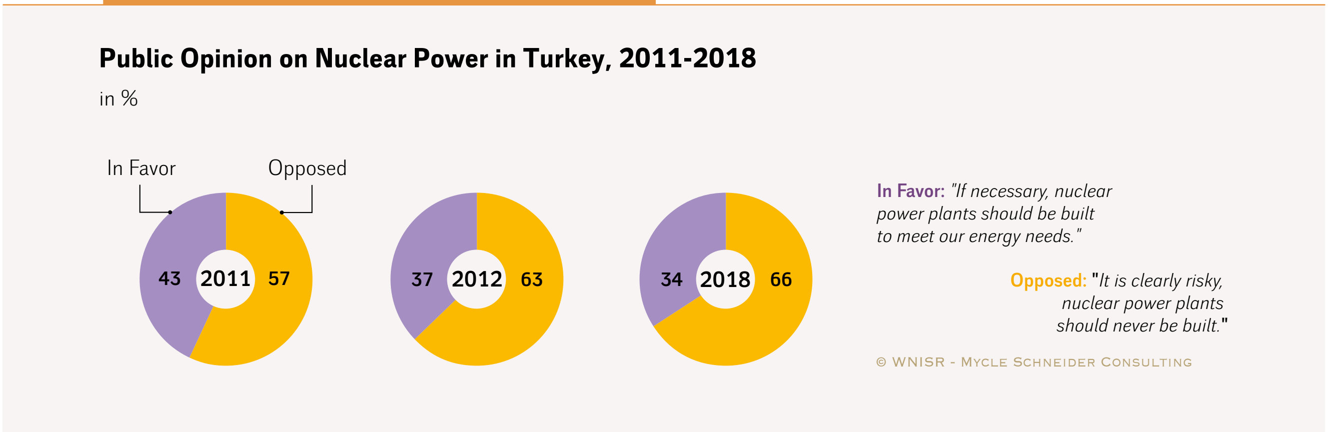
306 - Julia Harte, "Building of Turkey's First Nuclear Plant, Sited on a Fault Line, Facing Fresh Questions", *Reuters*, 25 March 2011, see https://www.reuters.com/article/idUS122778134920110325, accessed 15 May 2020.

307 - Servet Yanatma, "Türkiye'de halkın üçte ikisi nükleer santrallere karşı", *euronews*, 18 March 2019 (in Turkish), see https://tr.euronews.com/2019/03/18/turkiye-halkin-ucte-ikisi-nukleer-santrallere-karsi-ak-partililerde-destek-orani-yuzde-50, accessed 15 May 2020.

party in Turkey and an advocate of nuclear energy, half of its supporters are opposing nuclear power.

In another public survey in 2018, when asked the question "Assuming that a power plant will be built in the vicinity of your residence, which of the power plant options you oppose the most?" 67 percent of those surveyed selected nuclear.[308] In March 2020, a group of Turkish NGOs filed a court case against the Ministry of Environment and Urbanization to halt the construction work of the Akkuyu project because of the "lack of a valid environmental impact assessment and generation license".[309]

Figure 26 · Public Opinion in Turkey on Nuclear Power



Source: Euronews, 2019[310]

Repeated public opinion polls show that a growing majority of the surveyed Turkish citizens oppose the building of nuclear power plants in the country, regardless of political affiliations, as seen in Figure 26.

Jordan

In 2007, the Government established the Jordan Atomic Energy Commission (JAEC) and the Jordan Nuclear Regulatory Commission. JAEC started conducting a feasibility study on nuclear power, including a comparative cost-benefit analysis.[311]

In September 2014, JAEC and Rosatom signed a two-year development framework for a scheme, which was projected to cost under US$10 billion and generate electricity costing US$0.10/kWh.[312] However, in May 2018, an unnamed Jordanian Government official revealed to *The Jordan Times* that the plan to build two large reactors was not moving forward due

308 - *İklim Haber* and Konda Research, "Turkey Climate Survey", June 2018, see https://www.iklimhaber.org/climatesurvey2018/, accessed 15 May 2020.

309 - Ali Ekber ŞEN, "Akkuyu Nükleer Güç Santrali'ne durdurma davası", Hayat, 11 March 2020 (in Turkish), see https://www.sozcu.com.tr/hayatim/yasam-haberleri/akkuyu-nukleer-guc-santraline-durdurma-davasi/, accessed 15 May 2020.

310 - Servet Yanatma, "Türkiye'de halkın üçte ikisi nükleer santrallere karşı", *euronews*, 18 March 2019, see https://tr.euronews.com/2019/03/18/turkiye-halkin-ucte-ikisi-nukleer-santrallere-karsi-ak-partililerde-destek-orani-yuzde-50, accessed 26 August 2020.

311 - Mark Hibbs, "Jordan reactor siting study to be done in 2009, JAEC says", *Nucleonics Week*, 27 September 2007.

312 - *NIW*, "Briefs—Jordan", 18 April 2014.

to financial difficulties and that Jordan "is now focusing on small modular reactors".[313] This suggests not only that Jordan was unable to secure its part of the financing for the two 1000 MW proposal (~ US$5 billion, equivalent to 50.1 percent of the estimated project's cost)[314], but also that Russia did not prioritize the Jordanian project, compared to the financing facilities it offered Turkey and Egypt.

Since then Jordan has been focusing on small modular reactors. Jordanian officials reasoned that SMRs would be a better fit for the country because of the greater ease of financing, while their lower power capacity was also seen as more suited to Jordan's small electricity grid (~ 4 GW in 2018).[315] Additionally, the scarcity of water in Jordan seems to have contributed to the rationale to replace large reactor plans with those of SMRs.[316] It is reported that the chosen site for the SMR is Aqaba on the Red Sea, which had been previously ruled out, "due to its proximity to industrial and transportation infrastructure".[317]

Table 6 · Jordan's SMR agreements (as of May 2020)

Vendor / Entity	Year	Purpose / Scope
Rosatom (Russia)	2017	Cooperation
King Abdullah City for Atomic and Renewable Energy (Saudi Arabia)	2017	Cooperation / Feasibility study
Rolls Royce (U.K.)	2017	Feasibility study
CNNC (China)	2018	Cooperation framework
NuScale Power (USA)	2019	Feasibility study
X-energy (USA)	2019	Letter of intent

Sources: Various, compiled by WNISR, 2020.

Notes: CNNC = China National Nuclear Corporation.

Jordanian authorities have explored partnerships with several SMR vendors. Jordan has entered discussions with U.S.-based NuScale Power, U.K.-based Rolls Royce, China National Nuclear Corporation (CNNC), South Korea's Korea Atomic Energy Research Institute (KAERI), U.S.-based X-energy, and Russia's Rosatom.[318] However, it remains to be seen which, if any, of the partnerships will come to fruition. Additionally, JAEC has signed agreements with Saudi Arabia's KA-CARE, Rolls-Royce, and NuScale to carry out feasibility studies to

313 - Mohammad Ghazal, "Jordan to replace planned nuclear plant with smaller, cheaper facility", *Jordan Times*, 26 May 2018, see http://www.jordantimes.com/news/local/jordan-replace-planned-nuclear-plant-smaller-cheaper-facility, accessed 1 June 2018.

314 - WNA, "Nuclear Power in Jordan", Updated June 2019, see http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/jordan.aspx, accessed 29 June 2020.

315 - *WNN*, "IAEA launches project to examine economics of SMRs", 26 March 2020, see https://www.world-nuclear-news.org/Articles/IAEA-launches-project-to-examine-economics-of-SMRs; and *The Jordan Times*, "93 per cent of Jordan's electricity generated by natural gas", 5 May 2018, see http://www.jordantimes.com/news/local/93-cent-jordan%E2%80%99s-electricity-generated-natural-gas, both accessed April 2020.

316 - Rod Walton, "Jordan, NuScale Partnering on SMR Nuclear Feasibility Study", *Power Engineering*, 16 January 2019, see https://www.power-eng.com/2019/01/16/jordan-nuscale-partnering-on-smr-nuclear-feasibility-study/, accessed 11 April 2020.

317 - Joy Nasr and Ali Ahmad, "Middle East Nuclear Energy Monitor: Country Perspectives 2018", Energy Policy and Security Program, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, January 2019.

318 - *NEI*, "Jordan and X-energy agree to accelerate work on SMR", Nuclear Engineering International, 22 November 2019, see https://www.neimagazine.com/news/newsjordan-and-x-energy-agree-to-accelerate-work-on-smr-7527332, accessed 11 April 2020.

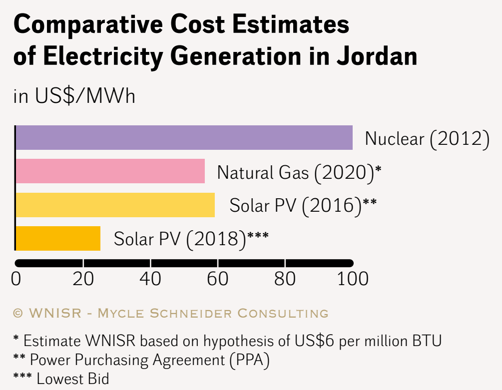
construct SMRs.[319] Of course, since none of these designs are ready, especially Rolls-Royce's, these feasibility studies can only be based on hypothetical numbers. Jordan's numerous SMR agreements and their scope are listed in Table 6.

Jordan's SMR Challenges

With its small grid size and limited financial resources, Jordan appears to be a textbook case for SMRs. The number and diversity of Jordan's SMR agreements shown in Table 6 signals the appetite of international vendors to engage with Jordan on the development of SMR in the country. Despite the enthusiasm, very little progress has been made in translating these agreements into actions. Like the large reactor proposal, Jordan's SMR venture is not without its own challenges[320], such as:

- Higher per kWh costs compared to large reactors due to diseconomies of scale;
- None of Jordan's SMR options are operational and many are first-of-a-kind designs;
- US-based vendors (and technologies) would require Jordan to sign the so-called "123 Agreement".

Figure 27 · Comparative Cost of Electricity in Jordan



Sources: Various, compiled by WNISR, 2020

If Jordan decided to build a nuclear power plant today, it would likely take at least 15 years to establish all the preconditions (legislation, safety authorities, trained staff, etc.), to construct and operate it. However, even at today's costs, solar photovoltaics (PV) and natural gas provide a cost-effective combination to generate electricity, lower than half of that generated by nuclear power. If Jordan takes on the SMR option as it is currently advocating, nuclear costs are expected to even grow substantially higher.

319 - *WNN*, "Jordan and Saudi Arabia team up on uranium, SMRs", 29 March 2017, see http://www.world-nuclear-news.org/Articles/Jordan-and-Saudi-Arabia-team-up-on-uranium,-SMRs; and *WNN*, "NuScale SMR to be considered for use in Jordan", 15 January 2019, see http://www.world-nuclear-news.org/Articles/NuScale-SMR-to-be-considered-for-use-in-Jordan, both accessed 24 June 2019; also *WNN*, "Rolls-Royce to conduct SMR study for Jordan", 9 November 2017, see http://www.world-nuclear-news.org/NN-Rolls-Royce-to-conduct-SMR-study-for-Jordan-09111702.html, accessed 24 April 2018.

320 - See M. V. Ramana and Ali Ahmad, "Wishful Thinking and Real Problems: Small Modular Reactors, Planning Constraints, and Nuclear Power in Jordan", *Energy Policy, 2016.*

Additionally, other SMR challenges are inherited from the large reactor option. As shown in Figure 27, electricity generated by nuclear power is not economically competitive vis-à-vis renewables or natural gas. The new gas discoveries in the Eastern Mediterranean signal Jordan's ability to reliably access relatively cheap natural gas. In 2019, Jordan signed a US$10 billion gas deal with Israel that would supply the kingdom's gas-fired power plants for the next 15 years.[321]

Like the large reactor option, SMR also face the challenge of public disapproval,[322] especially in the areas near the proposed site. In the current strained economic situation that has witnessed some of Jordan's biggest protests in recent history, pushing the nuclear option, large or small, may provoke strong opposition and prove politically costly.

Egypt

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-1970s, when the Nuclear Power Plants Authority (NPPA) was established. 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 coastline to host Egypt's first nuclear power plant.[323]

In recent years, Egypt has stepped up its efforts and 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. 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 through the sale of electricity. In December 2017, the total cost of the project was reported to be US$60 billion, including US$30 billion for reactor construction. 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.

The current phase is focused on site preparation and licensing. According to Anatolos Kovatnov, the head of engineering work at the Dabaa project, Rosatom has submitted all the documents required, and hopes to obtain the permits to start construction at the first unit of the Dabaa plant in 2020. In March 2019, the Egyptian NPPA granted the site a permit for the reactors, the first step toward getting a construction permit.[324]

321 - Suleiman Al-Khalidi, "Jordan gets first natural gas supplies from Israel", *Reuters*, 1 January 2020, see https://www.reuters.com/article/jordan-israel-gas-idUSL8N2960Q9, accessed 11 April 2020.

322 - Nadeem Goussous, "The Jordanian Nuclear Controversy", Centre international de formation européenne, 2019.

323 - 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 25 June 2019.

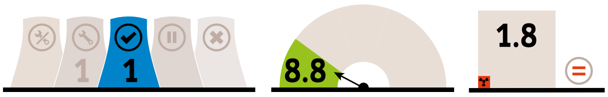
324 - *NEI*, "Egypt's El-Dabaa NPP granted site permit", 16 April 2019, see https://www.neimagazine.com/news/newsegypts-el-dabaa-npp-granted-site-permit-7156405/, accessed 14 June 2019.

In December 2019, Australian energy group Worley Limited was awarded a consultant contract to advise Egypt in the building process.[325] In February 2020, Atomstroyexport, a subsidiary of Rosatom, announced that three Egyptian firms—Petrojet, Hassan Allam, and Aran 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. Earlier in the month, Atomstroyexport had held a training for Egyptian engineers at the Kursk-II plant under construction in Russia.[326]

The Egyptian Government expects the Dabaa plant to be operational in 2026.[327] However, questions have been raised as to whether the Egyptian Nuclear and Radiological Regulatory Authority (ENRRA), established in 2010, will have the capacity and political independence to effectively oversee the project. 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 external debt.[328] The NGO Egyptian Initiative for Personal Right criticized the "persistent lack of transparency" that accompanied the nuclear project since its inception.

From the perspective of nuclear security, Egypt's nuclear program poses several challenges. 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".[329]

Iran



As of May 2020, Iran has the only operating nuclear power reactor in the Middle East (Bushehr-1), which became operational in 2011, 34 years after construction began. In 2019, the Bushehr-1 reactor generated 5.86 TWh, which is equivalent to 1.84 percent of the total electricity generated in Iran.[330]

In terms of generating capacity, the 915-MW Bushehr-1 reactor represents 1.3 percent (see Figure 28) in a mix dominated by oil and gas with 81.3 GW or just under 81 percent. Until Bushehr's Units 2 and 3 come online, the nuclear share is expected to decline as Iran ramps up its capacity of other sources to meet increasing electricity demand. Although the share of non-hydro renewables is just below 1 percent, it has doubled in one year.[331]

325 - *NEI*, "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 20 March 2020.

326 - *GCR*, "First contracts awarded for Egypt's $25bn Dabaa nuclear power station", *Global Construction Review*, 18 February 2020, see http://www.globalconstructionreview.com/news/first-contracts-awarded-egypts-25bn-dabaa-nuclear-/, accessed 20 March 2020.

327 - 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 20 March 2020.

328 - 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 20 March 2020.

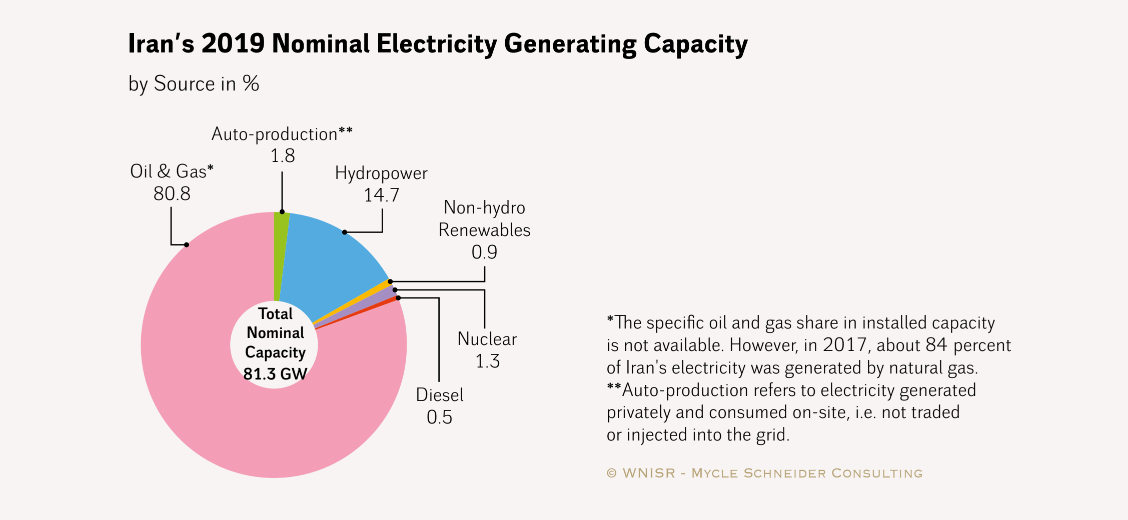
329 - Kareem Gerges and Ali Ahmad, "Egypt's Nuclear Power Program: Security and Economic Risks", Policy Brief #6/2018, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, October 2018, see https://www.aub.edu.lb/ifi/Documents/publications/policy_briefs/2018-2019/20181018_egypt_nuclear_power_program.pdf.

330 - IAEA-PRIS, "Country Profile: Iran", 2020, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=IR, accessed 17 May 2020.

331 - *BarghNews*, "سهم انرژی‌های تجدیدپذیر در تولید برق کشور چقدر است؟", see http://barghnews.com/fa/news/32512, accessed 18 May 2020.

Despite Iran's heavy economic and political investments in the nuclear program, nuclear power contributes only 1.3 percent to the country's electricity generating capacity—even private prosumers have a large capacity installed.

Figure 28 · Iran's 2019 Nominal Electricity Generating Capacity (by Source)



Source: ISNA, July 2019[332]

Compared to other countries in the region, Iran went beyond the mere goal of acquiring nuclear power reactors by investing in nuclear fuel chain activities such as uranium mining, enrichment and fuel manufacturing. Although Iran possess the capabilities to produce its own enriched uranium it cannot do so under the restrictions of the Joint Comprehensive Plan of Action (JCPOA). Although it remains to be seen if the agreement survives, Iran's stockpile of low enriched uranium is capped at 300 kg until 2030.

Beyond Bushehr Unit 1, in November 2014, Iran's Nuclear Power Production and Development Co. (NPPD) and Rosatom subsidiary Atomstroyexport signed a contract to build Bushehr Units 2 and 3. The Atomic Energy Organization of Iran (AEOI) projected that Units 2 and 3, would be completed within a 10-year timeline and cost around US$10 billion.[333]

Excavation for the foundation of the second unit at Bushehr—which is being built under a deal between Iran and Russia's Rosatom—started on 31 October 2017.[334] New basemat concrete for the reactor building, which signals official construction start, has been poured in November 2019. However, Unit 2 was originally part of the construction work of the Bushehr power plant, which started in 1976. In fact, in 1994, the IAEA had listed both Units 1 and 2 as "under construction".[335] As of May 2019, Iranian authorities had maintained that "Bushehr units 2 and 3 are to be completed in 2024 and 2026, respectively".[336] In April 2020, AEOI

332 - *ISNA*, "جدیدترین وضعیت تولید و مصرف برق - ایسنا", *Iranian Students' News Agency*, July 2019, see https://www.isna.ir/news/98050401733/, accessed 18 May 2020.

333 - Darrell Proctor, "Iran Expands Plans for Nuclear Power", *POWER Magazine*, 1 May 2019, see https://www.powermag.com/iran-expands-plans-for-nuclear-power/, accessed 13 April 2020.

334 - *NIW*, "Iran", 3 November 2017.

335 - WNISR, "Iran: Construction Restart of Busheer-2", World Nuclear Industry Status Report, 14 November 2019, see https://www.worldnuclearreport.org/Iran-Construction-Restart-of-Busheer-2.html, accessed 18 May 2020.

336 - *WNN*, "Rosatom committed to Iranian plant project", 9 May 2019, see http://world-nuclear-news.org/Articles/Rosatom-committed-to-Iranian-plant-project, accessed 13 June 2019.

spokesperson claimed that Bushehr-2 was 30 percent complete and the construction of Unit 3 would begin within two years.[337] As it is physically impossible to build almost one third of a nuclear power plant within five months, this is an indication that the current project is well based on earlier construction efforts.

Additionally, in 2016, Ali Akbar Salehi, Head of the AEOI, hinted at talks with China to build two more power plants in Darkhovain and on the Makran coast.[338] Since then, however, there has been no progress reported on these plans and their schedule, which is likely to be delayed further given the current economic and political environment.

Saudi Arabia has in the past raised concerns that potential radioactive leakage from the Bushehr plant could endanger the Gulf, including air, food and water supplies. Saudi Arabia, the UAE and other Gulf Cooperation Council or GCC states have voiced their concerns about Bushehr's safety on various occasions, especially after earthquakes.[339] In March 2020, Kazem Gharibabadi, Iran's ambassador to the Vienna-based international organizations, dismissed the Saudi concern as an attempt to politicize technical issues and maintained that the plant is meeting international safety standards.[340] Gharibabadi pointed to the IAEA's Integrated Regulatory Review Service (IRRS) mission at Bushehr in February 2020, the result of which was "satisfactory". He added that the IAEA delegation concluded that "Iran's nuclear safety system has the competence and capability to monitor nuclear activities".

The Evolving Role of Renewables and Natural Gas in the Middle East

Like in many parts around the world, an electricity mix that is based on the coupling between renewables and natural gas is gaining ground in the Middle East. In the six regional countries with nuclear power ambitions, natural gas is the main source of power generation. In three countries, natural gas contribution is more than 75 percent, in five over half (see Figure 29).

Development of renewable energy projects in the region is also thriving. Several world record-low prices have been set in Saudi Arabia and the United Arab Emirates (UAE) in recent years. As shown in Figure 30, Power Purchasing Agreement (PPA) *prices* of solar PV projects, which are naturally higher than the cost of generated electricity as they integrate a profit margin, are much cheaper than the *cost* estimates of nuclear electricity. This is not surprising since the costs of solar electricity (both for photovoltaic and concentrating solar plants) have witnessed dramatic decline over the past decade, while nuclear costs have gone up. Additionally, the region enjoys abundant solar resources, in terms of yield and number of sunny days per year, thanks to its geographic and climatic characteristics.

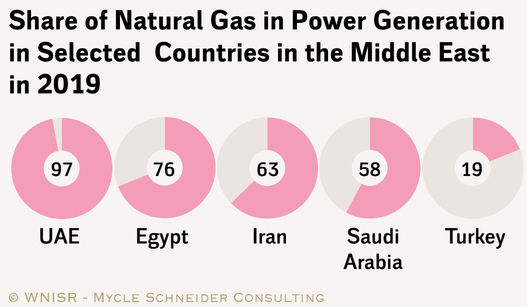
337 - *NEI*, "Iran pushes ahead with nuclear development despite pandemic restrictions", 15 April 2020, see https://www.neimagazine.com/news/newsiran-pushes-ahead-with-nuclear-development-despite-pandemic-restrictions-7871976, accessed 16 April 2020.

338 - *Tasnim News Agency*, "China to Build 2 Nuclear Power Plants in Iran: AEOI Chief", 19 January 2016, see https://www.tasnimnews.com/en/news/2016/01/19/975906/china-to-build-2-nuclear-power-plants-in-iran-aeoi-chief, accessed 13 April 2020.

339 - Elizabeth Dickinson, "UAE and Saudi Arabia call on Iran to allay nuclear plant fears", *The National*, 7 June 2013, see https://www.thenational.ae/world/mena/uae-and-saudi-arabia-call-on-iran-to-allay-nuclear-plant-fears-1.478749; and Amir Taheri, "Iran Earthquake Raises Concern over Nuclear Plant", *Asharq AL-awsat*, 16 November 2017, see https://english.aawsat.com/home/article/1085541/iran-earthquake-raises-concern-over-nuclear-plant, both accessed 18 May 2020.

340 - *Tehran Times*, "Iran dismisses Saudi claims over safety at Bushehr plant", 10 March 2020, see https://www.tehrantimes.com/news/445953/Iran-dismisses-Saudi-claims-over-safety-at-Bushehr-plant, accessed 13 April 2020.

Figure 29 · Share of Natural gas in Power Generation in Selected Regional Countries in 2019



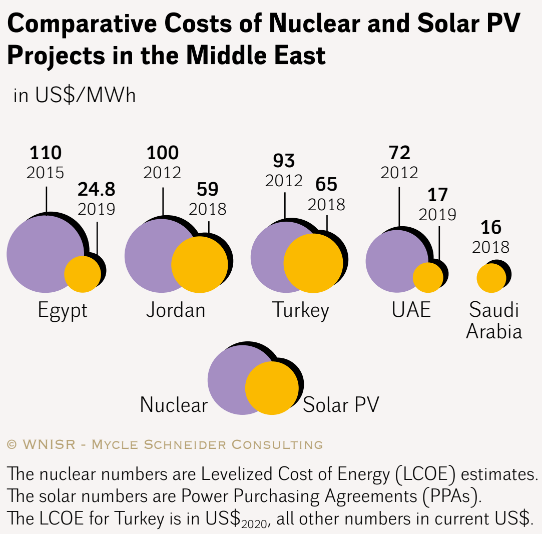
Source: BP, 2020

Notes: The BP data for 2019 does not include Jordan's value. In 2017, and according to the IEA, natural gas produced 83 percent of Jordan's electricity.

A recent study published in *Nature Energy*, analyzing the drivers of world record-low prices of renewable energy (especially solar PV) in the UAE and Saudi Arabia, found that among other factors favorable cost of capital and low taxes have played a significant role, emphasizing that "government policy remains an important element to remove barriers to PV deployment".[341]

In all nuclear-aspiring countries in the region, natural gas is currently the dominating fuel used in power generation. Because of their operational and loading flexibility, natural gas-fired power plants are complementary to the region's growing investments in renewable energy.

Figure 30 · Comparative Costs of Nuclear and Solar PV Projects in the Middle East



Sources: Various, compiled by WNISR, 2020

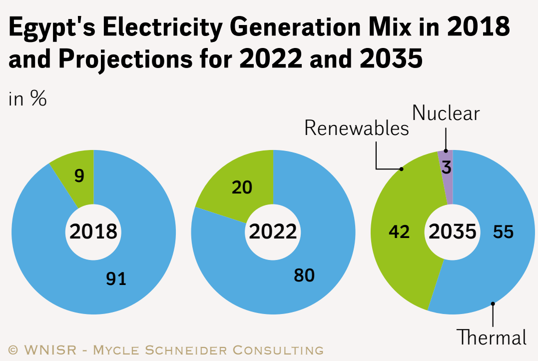
In all the regional countries with nuclear power aspirations, renewables have made big strides in recent years. Across the region, renewable energy targets are continually revised upwards.

341 - Harry Apostoleris et al., "Evaluating the factors that led to low-priced solar electricity projects in the Middle East", *Nature Energy*, 8 October 2018.

In **Egypt**, the installed capacity of non-hydropower renewables (solar and wind) was around 2.7 GW, as of December 2019.[342] In 2016, the Egyptian Government launched the "2035 Integrated Sustainable Energy Strategy", according to which it plans to generate 42 percent of the electricity through renewable energy sources, namely solar PV, concentrated solar-thermal power and wind energy (see Figure 31).[343] In the same strategy, the percentage allocated for nuclear energy is just 3 percent, raising questions about the real value for investing in nuclear electricity that is only going to have such a small overall contribution to the national power mix. 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.

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,[344] Egypt has invested in gas import and export infrastructure to position itself as regional hub, and in the process, become self-sufficient. 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. Despite the prioritization on renewables and natural gas, the Egyptian Government remains committed to building four nuclear reactors at the Dabaa site.

Figure 31 · Egypt's Electricity Generation Mix Projections for 2022 and 2035



Sources: Egypt's New and Renewable Energy Authority, 2016 / IEA, World Energy Balances, 2019

By 2035, Egypt's Dabaa nuclear power plant is projected to contribute only 3 percent of the country's electricity generation; a rather small share given the scale of investment (~US$60 billion – See section on Egypt above).

In the UAE, the Government released a long-term energy plan in February 2017, which proposes that by 2050 renewable energy will provide 44 percent of the country's electricity, with natural gas 38 percent, "clean fossil fuels" 12 percent and nuclear 6 percent.[345] The nuclear share is

342 - Mohamed Farag, "Egypt will produce 61,000MW of renewable energy, of which 12,000MW concentrated solar power", 28 December 2019, *Daily News Egypt*, see http://helioscsp.com/egypt-will-produce-61000mw-of-renewable-energy-of-which-12000mw-concentrated-solar-power/, accessed 14 April 2020.

343 - MNREA, "هيئة الطاقة الجديدة والمتجددة, أهداف الطاقة المتجددة", 2016, see http://nrea.gov.eg/test/en/About/Strategy, accessed 14 April 2020.

344 - *Reuters*, "UPDATE 1-Egypt's Zohr gas field output rises to 2.7 bln cubic feet per day - minister", 21 August 2019, see https://af.reuters.com/article/egyptNews/idAFL5N25H1VW, accessed 14 April 2020.

345 - LeAnne Graves, "UAE Energy Plan aims to cut CO2 emissions 70% by 2050", *The National*, 10 January 2017, see https://www.thenational.ae/uae/uae-energy-plan-aims-to-cut-co2-emissions-70-by-2050-1.51582, accessed 22 April 2018.

in line with expected output from the Barakah nuclear power plant and in September 2017, Government officials confirmed that there were no plans to build a second plant.[346]

In **Jordan**, where nuclear power plans continue to stumble, Energy Minister Hala Zawati said in late 2018 that renewable energy should provide more than 20 percent of the country's electricity by 2020[347], doubling the previous target,[348] and in December 2019, Minister Zawati said the soon-to-be-released energy strategy would include increasing the renewably electricity share to 30 percent by 2030.[349] In Jordan, the renewable energy market is one of the fastest growing in the Middle East. In December 2019, ACWA Power, a Saudi Arabian energy group, started the operation of a 50 MW solar power plant in Jordan with an electricity Power Purchase Agreement (PPA) price of US$59/kWh.[350] While the price level is significantly higher (yet) than in neighboring countries—mainly because of smaller unit size and higher financing costs—it is only about half the estimated levelized cost of electricity for a large reactor, even with favorable assumptions.[351] At the same time, the International Advisory Group, which is tasked with monitoring Jordan's progress in implementing its nuclear program, made an appeal for nuclear energy to remain part of the country's energy strategy in the medium and long term.[352]

In **Saudi Arabia**, the 300-MW Sakaka solar plant came on-line in November 2019, one month and a half ahead of schedule. The project was tendered only in February 2017. Owner-operator ACWA Power will sell electricity at US$23.6/MWh.[353]

Even in **Iran**, which has the region's most advanced nuclear power program, and despite being under heavy economic sanctions, renewable energy has been expanding. Iran's wind power capacity has grown from 92 MW in 2009 to 282 MW in 2018.[354] Likewise, solar energy capacity has gone from 1 MW in 2013 to 286 MW in 2018. However, this may be slowing because of U.S. sanctions imposed on Iran. One report from August 2018 recorded that solar projects amounting to 2.6 GW of capacity had been stalled because of U.S. sanctions.[355]

Sanctions aside, Iran has a high renewable energy potential. It has the advantage of the geographic location, which gives it access to several sources of renewable energy, including

346 - Amena Bahr, "UAE Abu Dhabi Unlikely to Build a Second Nuclear plant", *NIW*, 29 September 2017.

347 - *The Jordan Times*, "'20% of country's energy mix to be supplied from renewable sources by 2020'", 11 December 2018, see http://www.jordantimes.com/news/local/%E2%80%9820-countrys-energy-mix-be-supplied-renewable-sources-2020%E2%80%99, accessed 23 July 2019.

348 - International Trade Administration, "Jordan - Renewable Energy", U.S. Department of Commerce, Export.gov, 23 February 2017, see https://www.export.gov/article?id=Jordan-Renewable-Energy, accessed 7 May 2018.

349 - *Jordan Times*, "Gov't to increase renewable energy contribution in 2020-2030 strategy", 24 December 2019, see http://www.jordantimes.com/news/local/govt-increase-renewable-energy-contribution-2020-2030-strategy, accessed 11 April 2020.

350 - Emiliano Bellini, "ACWA Power switches on 50 MW solar park in Jordan", *PV Magazine International*, 12 December 2019, see https://www.pv-magazine.com/2019/12/12/acwa-power-switches-on-50-mw-solar-park-in-jordan/, accessed 11 April 2020.

351 - Ali Ahmad, "Economic risks of Jordan's nuclear program", *Energy for Sustainable Development*, Volume 29, 1 December 2015, see http://www.sciencedirect.com/science/article/pii/S0973082615000897, accessed 11 April 2020.

352 - *Jordan Times*, "Nuclear energy vital in Jordan energy strategy — IAG report", 29 December 2019, see http://jordantimes.com/news/local/nuclear-energy-vital-jordan-energy-strategy-%E2%80%94-iag-report, accessed 11 April 2020.

353 - Emiliano Bellini, "Saudi Arabia's 300 MW Sakaka solar plant comes online", PV Magazine International, 27 November 2019, see https://www.pv-magazine.com/2019/11/27/saudi-arabias-300-mw-sakaka-solar-plant-comes-online/, accessed 11 June 2020.

354 - IRENA, "Renewable Capacity Statistics 2019", March 2019, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf, accessed 3 April 2019.

355 - Tsvetomira Tsanova, "US sanctions hit 2.6 GW of solar projects in Iran - report", *Renewables Now*, 14 August 2018, see https://renewablesnow.com/news/us-sanctions-hit-26-gw-of-solar-projects-in-iran-report-623522/, accessed 13 June 2019.

solar, wind, hydropower and geothermal.[356] Recent studies have also shown that renewable energy can contribute to complete decarbonisation in Iran by 2050 by powering water desalination plants.[357] Distributed renewables are particularly advantageous in rural regions where the cost of transmission infrastructure and maintenance of centralized power plant are high.

In terms of its solar energy potential, Iran is exposed to approximately 300 sunny days per year with solar radiation average of 2,200 kWh per square meter.[358] According to official estimates, Iran's solar energy capacity potential is 40,000 GW,[359] an astonishingly high number.

Like Egypt, Iran continues to rely on natural gas as the main energy source which couples well with the country's renewable energy potential. Economically, this makes sense given the abundance of proven natural gas reserves and the impact of sanctions that prevents Iran from selling its gas abroad. Based on 2017 numbers, Iran is the third largest producer of natural gas and the fourth largest consumer in the world. However, the gas sector in Iran needs significant investments for it to keep up with the country's energy consumption. With the recent decline in Iran's economy due to tightening sanctions, Iran will find it difficult to finance in parallel a significant expansion of its nuclear program.

Impact of the COVID-19 Pandemic on Nuclear Programs in the Middle East

In the Middle East, the COVID-19 pandemic has had a varied impact on the regional nuclear power programs.

Beside the safety concerns outlined below, the COVID-19 pandemic is expected to weaken the already strained regional economies, putting further downward pressure on government budgets. This may force governments to reconsider their commitments when it comes to infrastructure spending such as on nuclear power programs. For example, **Saudi Arabia** is expecting its budget deficit to widen to around US$61 billion in 2020 as its revenues were hit hard by lower oil prices.[360] Countries like **Jordan**, which has already been under pressing economic conditions before the COVID-19 pandemic, will find it very difficult to invest in nuclear power projects, regardless whether large or small.

In terms of country-specific issues, in the **UAE**, Emirates Nuclear Energy Corporation (ENEC) has introduced measures such as locking down the Barakah site and halting "non-essential"

356 - Alireza Tavana et al., "Toward renewable and sustainable energies perspective in Iran", *Renewable Energy*, Volume 139, 1 August 2019, see http://www.sciencedirect.com/science/article/pii/S0960148119303271, accessed 13 April 2020.

357 - Narges Ghorbani, Arman Aghahosseini and Christian Breyer, "Assessment of a cost-optimal power system fully based on renewable energy for Iran by 2050 – Achieving zero greenhouse gas emissions and overcoming the water crisis", *Renewable Energy*, Volume 146, February 2020, see http://www.sciencedirect.com/science/article/pii/S0960148119309139, accessed 13 April 2020.

358 - Shiva Gorjian and Barat Ghobadian, "Solar Thermal Power Plants: Progress and Prospects in Iran", *Energy Procedia*, Volume 75, August 2015, see http://www.sciencedirect.com/science/article/pii/S1876610215012151, accessed 13 April 2020.

359 - Arash Mollahosseini et al., "Renewable energy management and market in Iran: A holistic review on current state and future demands", *Renewable and Sustainable Energy Reviews*, Volume 80, December 2017, see http://www.sciencedirect.com/science/article/pii/S136403211730881X, accessed 13 April 2020.

360 - Sam Bridge, "Saudi Arabia's budget deficit forecast to widen to $61bn on virus, oil rout", *Arabian Business*, 21 March 2020, see https://www.arabianbusiness.com/politics-economics/443369-saudi-arabias-budget-deficit-forecast-to-widen-to-61bn-on-virus-oil-rout, accessed 17 May 2020.

work in the wake of the pandemic.[361] Additionally, ENEC's Nawah company, the subsidiary responsible for Barakah's operation and maintenance, issued guidelines to reduce the number of workers at the plant and enforce social distancing. On the other hand, FANR, the UAE's nuclear regulator, established a COVID-19 crisis management taskforce, which called for measures such as asking employees to work remotely, leveraging digital means to conduct inspection and monitoring activities, and reducing the number of on-site inspectors.[362]

In **Iran**, **Turkey** and **Egypt**, where Russia's Rosatom is the nuclear technology vendor and provider of other services such as operation, fueling and training, there have been no announcements of COVID-19 impacts. However, some of Rosatom's operations in these countries may have been impacted by the company's announced COVID-19 measures, which included accommodating the need of some of its international employees to return home.[363]

In **Turkey**, an MP representing the Mersin province, where the Akkuyu power plant site is located, reported that one of the workers hads caught COVID-19, leading to some workers leaving the construction site, which hosted more than 5,000 workers, due to safety concerns.[364] Since then, members of local groups such as the Mersin Nuclear Platform have also voiced their concerns of the risks associated with continuing the construction works at Akkuyu during this period.[365]

In **Egypt**, Grigory Sosnin, director of the Dabaa project stated that preparatory work on site continues as planned and Rosatom "has taken a set of strict preventive measures" such as restricting access to the construction site.[366]

Barakah, a Model Replicable Throughout the Middle East?

Despite delays, the UAE's Barakah project has advanced faster than other regional projects; so why has the Emirati nuclear program progressed while other regional initiatives faltered?

The UAE, an oil-rich country with readily available financial resources and "high-grade" credit rating, bypassed this challenge. In contrast, other Middle Eastern countries lack access to affordable financing. Even for Saudi Arabia, a top oil-producer, which usually enjoys an easier access to capital, is under economic pressure due to the collapse of oil prices. In projects with vendor financing, like Egypt and Turkey's deals with Russia's Rosatom, there is a perceived risk around Rosatom's ability to deliver, especially if the Russian economy continues to suffer from the combined consequences of low oil prices and the COVID-19 pandemic. The Russian

361 - *WNN*, "ENEC CEO: Barakah Plant to Start up 'Very Soon'", 7 May 2020, see https://world-nuclear-news.org/Articles/ENEC-CEO-Barakah-to-start-up-very-soon, accessed 14 May 2020.

362 - Christer Viktorsson, "Viewpoint: Regulators are adapting to an unprecedented challenge", *WNN*, 11 May 2020, see https://world-nuclear-news.org/Articles/Viewpoint-Regulators-adapt-to-an-unprecedented-cha, accessed 11 May 2020.

363 - Rosatom, "Rosatom State Atomi Energy Corporation ROSATOM global leader in nuclear technologies nuclear energy", 7 April 2020, see https://www.rosatom.ru/en/press-centre/news/rosatom-arranged-the-return-of-178-employees-from-construction-site-of-rooppur-npp-bangladesh-to-rus/, accessed 17 May 2020.

364 - HABERCi, "AKKUYU'DA COVİD-19 İDDİASI!", *Mersin Haberci Gazetesi*, 22 April 2020 (in Turkish), see http://www.mersinhaberci.com/haber/21748/akkuyuda-covid-19-iddiasi.html, accessed 17 May 2020.

365 - Ali Ekber ŞEN, "5 binden fazla işçinin çalıştığı Akkuyu'da corona çıktı", Sözcü, 10 April 2020 (in Turkish), see https://www.sozcu.com.tr/2020/gundem/5-binden-fazla-iscinin-calistigi-akkuyuda-corona-cikti-5740045/, accessed 17 May 2020.

366 - Mohammed Abdo Hasanein, "Egypt's Nuclear Plant Project Continues Despite Virus Restrictions", *Asharq al-Awsat*, 5 May 2020, see https://english.aawsat.com/home/article/2268716/egypt%E2%80%99s-nuclear-plant-project-continues-despite-virus-restrictions, accessed 17 May 2020.

Government has been subsidizing Rosatom's projects overseas by providing government-to-government loans as well as sovereign guarantees.

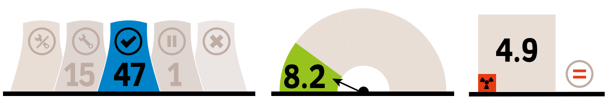
As early as 2009, ENEC, FANR, and the Khalifa University for Science, Technology and Research (KUSTAR) announced a Nuclear Energy Scholarship Program for Emirati students, promising graduates lucrative and prestigious positions in the nuclear industry.[367] Officials also held a number of public forums to provide information and updates on the project.[368] Moreover, the UAE's leadership made special efforts to build a wide network of institutions and stakeholders with a vested interest in the success of the nuclear program, thus defusing much of the potential pushback. Efforts to sell the nuclear narrative to the public have been either weak or non-existent in other countries in the region. In Jordan, Turkey, and, to some extent, in Egypt, the public has been vocal in its criticisms of proposed nuclear projects.

Some of the proposed nuclear projects in the region face political barriers related to nuclear non-proliferation. The UAE bypassed much of the controversy associated with other nuclear projects in the region by agreeing to forgo uranium enrichment and reprocessing of nuclear spent fuel.[369] This has removed political and logistical challenges related to establishing a broader nuclear infrastructure, which otherwise might have delayed or halted the project.

In some respects, the UAE's nuclear program can be perceived as a "counter-Iran" model, wherein stripping the nuclear program of its most sensitive parts is "rewarded" by access to state-of-the-art technologies and wider international support, especially from the United States. Egypt and Turkey seem to be contemplating a similar approach, since their respective deals with Russia include fuel supply and take-back of spent nuclear fuel.

In conclusion, the expansion of nuclear power in the Middle East introduces more challenges than opportunities in a region swept by conflicts, fragility and economic hardship. The region's weak institutions, especially the regulatory ones, and its geopolitical volatility pose serious safety and security concerns that extend beyond the borders of the countries where nuclear power plants are being built or projected. Economically, the region is already embarking on an energy transition away from oil by investing heavily in a power generation capacity of natural gas and renewables. Except for the case of the UAE, and based on the current electricity mix, the addition of nuclear power does not seem to be contributing much to the region's energy transition.

CHINA FOCUS



China continues to expand its nuclear power sector, albeit at a much slower pace than the nation's renewable sector. As of mid-2020, China had 47 reactors in operation, with a total generating capacity of 45.5 GW. In addition, the 20-MW China Experimental Fast

367 - ENEC, "UAE Nuclear Energy Scholarship Now Accepting Applications", 20 December 2010, see https://www.enec.gov.ae/news/latest-news/uae-nuclear-energy-scholarship-program-now-accepting-applications/, accessed 13 April 2020.

368 - *WNN*, "UAE nuclear program reaches out to public", 16 December 2014, see https://world-nuclear-news.org/Articles/UAE-nuclear-program-reaches-out-to-public, accessed 13 April 2020.

369 - However, the UAE does not yet have an adopted long-term spent nuclear fuel policy.

Reactor (CEFR) remains in LTO. While in July 2019, Rosatom reported the delivery of a batch of fuel to the facility,[370] there was no announcement of a restart of the reactor.

In 2019, nuclear power contributed 330 TWh of electricity production, which constituted 4.9 percent of all electricity generated in China. These figures have increased from the previous year, by 53.1 TWh (+19.2 percent) and 0.7 percentage points respectively.

Despite this increase, there seems profound uncertainty about the future path of nuclear power in China. *Nuclear Intelligence Weekly* (*NIW*) reported in July 2020 that "China's ultimate authority, the State Council, has mentioned almost nothing about newbuilds in its Government work plan; while the National Energy Administration (NEA) provided no details of new nuclear construction in its recent 2020 National Energy Work Guiding Opinions, unlike in previous years".[371]

This uncertainty is best illustrated by what is known (and unknown) about reactor construction. The IAEA's PRIS database indicated as of 4 May 2020 that there were 10 reactors under construction with a total capacity of 9.4 GW.[372] In the second half of May 2020, this was updated to include the start of construction of Taipingling-1 (also called Huizhou-1). However, the construction start of this reactor actually took place in December 2019, and had been publicly reported since at least January 2020.[373] CGN Power (part of China General Nuclear Power Corporation – CGNPC) also mentioned the construction start in its annual report in April 2020.[374]

Even more mysterious is the inaugural CAP1400 project at Shidao Bay that is being built by State Power Investment and that was first revealed by *Nuclear Intelligence Weekly* last year, based on a list of all nuclear plants operating or considered as under construction as of 13 June 2019 put out by the National Nuclear Safety Administration.[375] In January 2020, *NIW* noted that the project had been "kicked off… in an unusually quiet fashion, with no official announcements either from the government or the developer" and that there were "no announced target dates for commercial operation".[376] As of 1 July 2020, IAEA-PRIS only reports the twin High-Temperature Reactors Pebble-bed Module (HTR-PM) as being under construction at the Shidao Bay site. In previous WNISR editions, Shidao Bay-1 has been accounted for as one unit, just as the IAEA's PRIS indicates the plant as consisting of one 200-MW unit.[377] However, it turns out that Shidao Bay-1 (also called Shidaowan-1) consists of two 100-MW reactors, and

370 - Rosatom, "TVEL Fuel Company of ROSATOM Supplied Fuel for China Experimental Fast Reactor", Press Release, 9 July 2019, see https://www.rosatom.ru/en/press-centre/news/tvel-fuel-company-of-rosatom-supplied-fuel-for-china-experimental-fast-reactor-/, accessed 25 July 2019.

371 - C.F. Yu, "Beijing's Silence On Further Newbuilds", *Nuclear Intelligence Weekly, 2 July 2020.*

372 - IAEA, "Power Reactor Information System (PRIS) Database", see http://www.iaea.org/programmes/a2/, accessed 4 May 2020.

373 - Miaosu Li, "China Nuclear News Roundup - January 2020", Nicobar Group, 21 January 2020, see http://www.nicobargroup.com/news-views-1, accessed 6 May 2020.

374 - CGN Power, "Annual Report 2019", China General Nuclear Power Corporation, April 2020, see http://en.cgnp.com.cn/encgnp/c100882/202004/f3c20533b65c4cf3a41583190c02057c/files/a5bc0c2ac79c425398a2296b2b054005.pdf, accessed 2 April 2020.

375 - *NIW, "Why the Secrecy Over Reactor Construction Start?", 12 July 2019.*

376 - C.F. Yu, "Can China Meet Bullish Nuclear Growth Targets?", *Nuclear Intelligence Weekly, 10 January 2020.*

377 - IAEA-PRIS, see https://pris.iaea.org/pris/CountryStatistics/ReactorDetails.aspx?current=957, accessed 8 June 2020.

consequently, as of WNISR2020, they are considered separately, i.o.w. as two units under construction (Shidao Bay 1-1 and 1-2).[378]

The China Fast Reactor (CFR-600) has also reportedly been under construction since December 2017,[379] but is not listed by IAEA-PRIS as of mid-2020. Here again, there are various reports that suggest that construction is ongoing. In January 2019, Russia's *TASS News Agency* reported that Rosatom subsidiary TVEL had signed "a contract for supply of nuclear fuel for CFR-600 fast-neutron reactor which is currently under construction".[380] In May 2020, a Chinese expert used satellite imagery to identify "the reprocessing plant [that] will supply plutonium for the mixed-oxide fuels that will power the CFR-600 demonstration fast reactors currently under construction".[381]

Another sign of uncertainty about the future of nuclear power in China is the decline in numbers. Even with these additional reactors counted by WNISR as being under construction, the current number of 15 represents a continuous decline over the corresponding numbers of 17 reported in WNISR2018 and 21 in WNISR2017.[382] The decline highlights the slowdown of China's nuclear power program, especially considering the target of the 5-Year Plan 2016–2020: the 15 units combine less than 14 GW while 30 GW were planned for as under construction simultaneously by the end of the period.

There are structural reasons for this slowdown. As previous issues of WNISR have discussed, China has been confronting a combination of overcapacity in the power market and a reduced rate of demand growth. These problems might be further compounded by the COVID-19 pandemic, which, as in other countries, had a significant impact on electricity demand.[383] China experienced a 7.8 percent cumulative drop in power consumption in January and February 2020.[384] However, by May 2020, demand seemed to be back to pre-lockdown levels.[385]

A separate problem for nuclear power has been the Government's lowering of electricity prices, especially for industrial consumers, in recent years.[386] In combination with nuclear construction cost overruns, this makes the outlook for nuclear power "cloudier".[387] A more recent difficulty has arisen with the strain in U.S.-China relations and the Trump administration's ban on

378 - This is also in order to be coherent with the precedent of the Akademik Lomonosov, the Russian "floating" nuclear plant, consisting of two 30-MW reactors, and identified as two separate units by IAEA-PRIS.

379 - *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.

380 - *TASS*, "Rosatom eyes supplying nuclear fuel for China's new fast neutron reactor", 10 January 2019, see https://tass.com/economy/1039341, accessed 13 May 2020.

381 - Hui Zhang, "Pinpointing China's new plutonium reprocessing plant", *Bulletin of the Atomic Scientists*, 5 May 2020, see https://thebulletin.org/2020/05/pinpointing-chinas-new-plutonium-reprocessing-plant/, accessed 13 May 2020.

382 - WNISR2020 is accounting for two instead of one Shidao Bay-1 units, which adds one unit to the WNISR2017–19 numbers

383 - Muyu Xu and Tony Munroe, "Electric Shock: China Power Demand Drops as Coronavirus Shutters Plants", *Reuters*, as published in *US News & World Report*, 14 February 2020, see https://www.usnews.com/news/world/articles/2020-02-14/electric-shock-china-power-demand-drops-as-coronavirus-shutters-plants, accessed 31 May 2020.

384 - *IHS Markit*, "Power Demand Coming Back in China After Unprecedented Drop During COVID-19 Lockdown", 30 March 2020, see https://news.ihsmarkit.com/prviewer/release_only/slug/2020-03-30-power-demand-coming-back-in-china-after-unprecedented-drop-during-covid-19-lockdown, accessed 27 April 2020.

385 - IEA, "Covid-19 impact on electricity", Statistics Report, Updated August 2020, see https://www.iea.org/reports/covid-19-impact-on-electricity, accessed 17 August 2020.

386 - Mo Yelin, "Quick Take: China Cuts Industrial Electricity Charges Again", *Caixin Global*, 17 May 2018, see https://www.caixinglobal.com/2018-05-17/quick-take-china-cuts-industrial-electricity-charges-again-101251692.html, accessed 31 May 2020.

387 - C.F. Yu, "Can China Meet Bullish Nuclear Growth Targets?", *Nuclear Intelligence Weekly*, 10 January 2020.

most nuclear exports to China.[388] This means that China is forced to avoid the use of any U.S. suppliers. A number of new-build projects in China that planned to construct AP1000 reactors are reportedly "caught in the political minefield of US-China relations due to their technology choice".[389]

Of the 15 reactors currently under construction, the two at the Shidao Bay 1 project have been underway since 2012, six since 2015 (Fangchenggang-3, Fuqing-5 and -6, Hongyanhe-5 and -6, and Tianwan-5), two since 2016 (Fangchenggang-4 and Tianwan-6), one since 2017 (CFR-600), four since 2019 (Huizhou/Taipingling-1, Zhangzhou-1, and Shidao Bay 2-1 & 2-2[390]). Many of these are delayed (see Annex 5) and these delays may be part of the reason for not publicizing new construction starts.

The last round of highly publicized construction projects involved the EPR and the AP1000 reactor designs, which were all quite delayed compared to initial projections, as detailed in previous issues of the WNISR. Their performance after commissioning has also been somewhat mixed, with Sanmen-2, one of the four inaugural AP1000 reactors, being shut down only six weeks after commercial operations began in November 2018 because of water intrusion into a reactor coolant pump.[391] So far, the reasons for the pump malfunction have not been made public. China National Nuclear Corp (CNNC) announced in November 2019 that the reactor had "entered into the restart phase, with nuclear fuel already loaded into the reactor,"[392] and the PRIS database records that Sanmen-2 was online for a mere 817 hours (around 34 days) during all of 2019.

Among the reactors under construction, CGN has announced that Hongyanhe Units 5 and 6, both of the ACPR-1000 design, are expected to commence operations in the "second half of 2021 and the first half of 2022" respectively.[393] That is around one year later than predicted in CGN's Annual Report for 2015 (second half of 2020 and 2021 respectively).[394]

CGN has also announced that the Hualong units it is constructing at Fangchenggang (Units 3 and 4) are expected to "commence operations" in 2022.[395] Again, this is delayed compared to earlier predictions of operations starting in 2020.[396]

CNNC's Hualong projects at Fuqing, Units 5 and 6, also appear to be delayed. When concrete was poured for Fuqing-6, the expectation was that they "would be completed in 2019 and 2020,

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

389 - C.F. Yu, "Beijing's Silence On Further Newbuilds", *NIW*, 2 July 2020, p.5.

390 - Provisional names for the two reactors at Rongcheng/Shidaowan.

391 - C.F. Yu, "Sanmen-2 Restart Puts CNNC Out of Its Financial Misery", *Nuclear Intelligence Weekly*, 22 November 2019.

392 - *NIW*, "Sanmen-2 Prepares to Restart", 15 November 2019.

393 - CGN, "Inside Information – Operation Briefings for the First Quarter of 2020", 9 April 2020, see http://en.cgnp.com.cn/encgnp/c20191226/202004/b6c32f917fe240549f40b9f150ec3352/files/e972209f38a44403ac1d5a030affdedf.pdf, accessed 20 April 2020.

394 - CGN, "2015 Annual Report", 2016, see http://en.cgnp.com.cn/encgnp/c100882/201709/37ddeb8c24ba48d7a192b171d42a00d5/files/60c25f8d89cd4ec4b8a8b62a71bb9382.pdf, accessed 8 June 2020.

395 - CGN, "Inside Information – Operation Briefings for the First Quarter of 2020", 9 April 2020, see http://en.cgnp.com.cn/encgnp/c20191226/202004/b6c32f917fe240549f40b9f150ec3352/files/e972209f38a44403ac1d5a030affdedf.pdf, accessed 20 April 2020.

396 - *NEI*, "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.

respectively".[397] In a March 2020 update, CNNC announced that Fuqing-5 had cleared its first hot performance test.[398]

CNNC's Tianwan-5 and -6 are of the ACPR-1000 design and are reported to be scheduled for commercial operation in 2020 and 2021.[399] That remains in line with initial expectations when construction started.[400]

Finally, the twin High-Temperature Reactors (HTRs) being constructed at Shandong continue to be delayed. Although the plant was supposed to start generating commercial electricity by the end of 2017, according to a June 2020 presentation, "criticality and power operation" are scheduled for 2021.[401] There appear to be no plans in China to construct any more HTRs, certainly not of the same design. Economics is likely a key reason. The projected costs of electricity generation at the HTR are nearly 40 percent higher than at light water reactors,[402] without accounting for many additional years of delays and thus much higher financing costs than anticipated.

Although the country was the first to be affected by the COVID-19 pandemic, Chinese authorities maintain that it will not impact nuclear reactor construction.[403] This remains to be seen.

Success of these Hualong construction projects is pivotal to plans to export the technology to other countries, especially in Europe. The main prospect for such exports seems to be the United Kingdom. The U.K. Office for Nuclear Regulation (ONR) announced in February 2020 that it had completed Step 3 of the Generic Design Assessment (GDA) of the Hualong, or more precisely the U.K. version of the design. The review did not identify "any fundamental safety or security shortfalls that would prevent" the reactor being given a Design Acceptance Confirmation (DAC), ONR stated that it had identified "a number of areas for which further substantiation is needed from the Requesting Party" and more generally "a lot of work by the Requesting Party is still required".[404]

The progress in the U.K. was in contrast to what happened across the continent. In May 2020, the Romanian Government "asked the state company Nuclearelectrica... to terminate negotiations with...China General Nuclear Power Corporation...on the construction of nuclear

397 - *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.

398 - *Nuclear Energy Insider*, "China's CNNC Completes First Hot Performance Test at Fuqing 5", *Reuters*, 18 March 2020, see https://analysis.nuclearenergyinsider.com/node/55182, accessed 6 May 2020.

399 - *NEI*, "China delays operation of Hongyanhe 5&6", *Nuclear Engineering International*, 9 January 2020, see https://www.neimagazine.com/news/newschina-delays-operation-of-hongyanhe-56-7591603, accessed 31 May 2020.

400 - *WNN*, "Construction starts on sixth Tianwan unit", 7 September 2016, see https://www.world-nuclear-news.org/Articles/Construction-starts-on-sixth-Tianwan-unit, accessed 31 May 2020.

401 - Fu Li, "Chinese HTR Program", Institute of Nuclear and New Energy Technology, Tsinghua University, Presentation at the Webinar #4 – SMR Vendor Forum "An Open Discussion with Global Vendors to Review Designs and Benefits", International Framework for Nuclear Energy Cooperation, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 5 July 2020.

402 - C. F. Yu, "CNEC-CFHI Deal — Boosting the HTGR Or Chinese Manufacturing?", *Nuclear Intelligence Weekly*, 9 September 2016.

403 - Muyu Xu and David Stanway, "China says virus outbreak will not impact nuclear power plant construction", *Reuters*, 15 April 2020, see https://www.zawya.com/mena/en/business/story/China_says_virus_outbreak_will_not_impact_nuclear_power_plant_construction-TR20200415nL3N2C311BX1/, accessed 27 May 2020.

404 - ONR, "UK HPR1000 progresses to next stage of assessment", Office for Nuclear Regulation, 13 February 2020, see http://news.onr.org.uk/2020/02/uk-hpr1000-progresses-to-next-stage-of-assessment/, accessed 29 April 2020.

reactors 3 and 4 at Cernavoda".[405] The two companies had signed a "preliminary agreement for the construction and operation of two new reactors" only in May 2019[406] (see section on Romania in Annex 1).

Meanwhile, renewable energy capacity in China continues to grow at a substantially higher rate. Total installed renewable capacity increased by about nine percent from 2018 to 2019, going from 695 GW to 759 GW; wind capacity expanding from 185 GW in 2018 to 210 GW in 2019, and solar capacity from 175 GW in 2018 to 205 GW in 2019.[407]

According to the China Electricity Council, the two forms of renewable energy provided 406 TWh (wind) and 224 TWh (solar) to the grid respectively.[408] These figures agree with those reported by BP.[409] These have gone up by almost 11 percent and 26.6 percent compared to 2018. Electricity generated by wind continues to exceed the nuclear contribution, and solar energy is approaching two-thirds of nuclear energy's contribution. (See Nuclear Power vs. Renewable Energy). *IHS Markit* estimates that in January and February 2020, due to the impact of the COVID-19 pandemic, nuclear energy's contribution to the grid declined by 2.2 percent whereas renewables have remained resilient, with wind and solar energy growing by 0.9 percent and 12 percent respectively.[410]

In November 2019, the Government of China scaled back the subsidies offered to renewable power, from 8.1 billion yuan (US$1.2 billion) in 2019 to 5.67 billion yuan in 2020 (US$0.8 billion).[411] This is in part a recognition of the increasing economic competitiveness of renewable energy. In May 2019, the National Development and Reform Commission (NDRC) announced that wind projects commissioned after 1 January 2021 will not receive subsidies and will apply what it terms "grid price parity", namely that it will be paid the same as coal.[412]

A different development in the future might be the acceleration of offshore wind energy, which has grown in installed capacity from 0.1 GW in 2010 to 5.9 GW in 2019.[413] Last year, the inaugural price competition for offshore wind development led to a winning bid of 620 yuan/MWh (US$87.8/MWh) from China Longyuan, the wind development arm of China Energy Investment Corporation.[414] The potential for offshore wind power is considerable and a recent

405 - Madalin Necsutu, "Romania Cancels Deal With China to Build Nuclear Reactors", *Balkan Insight*, 27 May 2020, see https://balkaninsight.com/2020/05/27/romania-cancels-deal-with-china-to-build-nuclear-reactors/, accessed 31 May 2020.

406 - *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 15 May 2020.

407 - IRENA, "Renewable Capacity Statistics 2020", International Renewable Energy Agency, 2020 (in English, French and Spanish), see https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020, accessed 24 April 2020.

408 - China Electricity Council, "2019 electricity & other energy statistics (preliminary)", *China Energy Portal*, 21 January 2020 (English Translation), see https://chinaenergyportal.org/2019-electricity-other-energy-statistics-preliminary/, accessed 13 May 2020.

409 - BP, "Statistical Review of World Energy 2020", June 2020, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 17 June 2020.

410 - Xizhou Zhou, "Renewables Emerge as Winner During China's COVID-19 Lockdown", *IHS Markit*, 26 March 2020, see https://ihsmarkit.com/research-analysis/renewables-emerge-as-winner-during-chinas-covid19-lockdown.html, accessed 27 April 2020.

411 - Muyu Xu and Dominique Patton, "China to cut renewable power subsidy to $807 million in 2020", *Reuters*, 20 November 2019, see https://www.reuters.com/article/us-china-renewables-subsidy-idUSKBN1XU0X8, accessed 27 April 2020.

412 - David Stanway, "China to end subsidies for onshore wind power by 2021", *Reuters*, 24 May 2019, see https://www.reuters.com/article/us-china-windpower-idUSKCN1SU0M1, accessed 13 May 2020; Joyce Lee and Feng Zhao, "Global Wind Report 2019", Global Wind Energy Council, March 2020, see https://gwec.net/global-wind-report-2019/, accessed 27 April 2020.

413 - IRENA, Renewable Capacity Statistics 2020, p.20.

414 - Yuki Yu, "China offshore wind bid under $100/MWh in first price contest", *Recharge News*, 23 August 2019, see https://www.rechargenews.com/wind/china-offshore-wind-bid-under-100-mwh-in-first-price-contest/2-1-659416, accessed 31 May 2020.

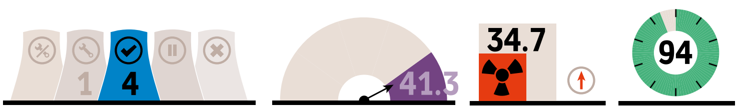
study estimates that thousands of GW of capacity and over 10,000 TWh could be supplied at costs lower than the estimated costs of generating nuclear power.[415]

Another sign of the growing importance of renewable energy is interest among domestic nuclear companies in wind and solar power. Two of the three traditional state owned nuclear enterprises, the State Power Investment Corporation (SPIC) and CGN are now the largest solar photovoltaic power producer globally and the fourth-biggest wind developer respectively.[416] CGN and China Huaneng, which is developing the HTR-PM (High-Temperature gas-cooled Reactor Pebble-bed Module) in Shidaowan, also bid in the first offshore wind power competition but were unsuccessful.[417]

These renewable energy acquisitions might also affect how these entities evolve in the future, especially as the Chinese Government is trying to respond to the country's economic downturn by consolidating and restructuring the energy industry.[418] Such restructuring could dramatically shape the future of the nuclear energy sector. Since the 1990s, the growth of nuclear power in China has been fueled by competition between the leading state-owned enterprises involved in the development of nuclear power, CGN, SPIC and CNNC.[419] There is now speculation about forging "a unified nuclear developer by consolidating all the nuclear power assets of CNNC, CGN, and SPIC" or, as an alternative, having CGN's nuclear units be absorbed by CNNC while SPIC absorbs the renewable units.[420]

China's renewable energy push has also extended outside its borders. Since 2014, Chinese equity investment has supported a total of 12.6 GW of wind and solar projects in South and Southeast Asia as part of the Belt and Road Initiative.[421] Chinese companies also built and own large renewable energy projects in various European countries.

FINLAND FOCUS



Finland operates four units which in 2019 supplied 22.9 TWh of electricity, the highest production ever in the country. The nuclear share represented 34.7 percent of the nation's electricity in 2019, an increase of 2.3 percentage points over the previous year but remaining below the highest share of 38.4 percent in 1986. Finland's fifth reactor, the 1.6 GW EPR at Olkiluoto (OL3), which has been under construction since August 2005, was originally scheduled to begin operations in 2009, and during the past year has suffered further multiple

415 - Peter Sherman, Xinyu Chen and Michael McElroy, "Offshore wind: An opportunity for cost-competitive decarbonization of China's energy economy", *Science Advances, 1 February 2020.*

416 - C.F. Yu, "China's Datang Approves Second Controlling Stake in a Newbuild", *NIW*, 2 December 2019.

417 - Yuki Yu, "China Offshore Wind Bid under $100/MWh in First Price Contest", *Recharge News*, 23 August 2019.

418 - C.F. Yu, "CGN Once Again at the Center of Restructuring Rumors", *NIW*, 20 March 2020.

419 - M.V. Ramana and Eri Saikawa, "Choosing a standard reactor: International competition and domestic politics in Chinese nuclear policy", Energy, December 2011.

420 - C.F. Yu, "CGN Once Again at the Center of Restructuring Rumors", *NIW*, 20 March 2020.

421 - Greenpeace International, "Chinese Equity Investments in Energy Reshape South and Southeast Asia", Greenpeace International, 29 July 2019, see https://www.greenpeace.org/international/press-release/23446/chinese-equity-investments-in-energy-reshape-south-and-southeast-asia-greenpeace-analysis, accessed 24 April 2020.

delays.[422] The latest schedule, as of mid- 2020, is for grid connection at the end of January 2021 and commercial operation by 31 May 2021, 16 years after construction start and 12 years later than originally planned.[423] The prospects are for further delays.

Teollisuuden Voima Oyj (TVO), which owns and operates the Olkiluoto nuclear power plant, reported record generation for its Olkiluoto Units 1 (OL1) and 2 (OL2) reactors, with total generation of 14.75 TWh and with load factors of 96.9 percent and 92.7 percent, respectively.[424] Fortum, the operator of the two reactors at Loviisa also reported record production at Loviisa Unit 1, with total production from the plant of 8.2 TWh.[425]

Finland has adopted different nuclear technologies and suppliers, as two of its operating reactors are VVERs (Vodo-Vodianoï Energuetitcheski Reaktor) 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. The average age of the four operating reactors is 41.3 years. In January 2017, operator TVO filed an application for a 20-year license extension for the respectively 39 and 37-year old units Olkiluoto-1 and -2.[426] On 20 September 2018, the Cabinet approved the lifetime extension for TVO's OL1 and OL2 to operate until 2038.[427]

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,[428] and then in April 2014 a "binding decision to construct" a 1200 MW AES-2006 reactor was announced. A construction license for the reactor is expected in 2021[429] and construction is to begin in the same year, with operation of the plant currently scheduled for 2028. As reported in WNISR2019, with construction of the nuclear plant not yet started, the Hanhikivi-1 project is already nine years behind the original schedule.[430]

Olkiluoto-3 (OL3)

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

422 - YLE, "Third Olkiluoto nuclear reactor granted operating license", 8 March 2019, see https://yle.fi/uutiset/osasto/news/third_olkiluoto_nuclear_reactor_granted_operating_license/10680697, accessed 9 July 2020.

423 - Roger Fry, "TVO reporte le démarrage d'Olkiluoto 3 (1,6 GW) à mai 2021", *Montel*, 2 July 2020 (in French), see https://www.montelnews.com/fr/story/tvo-reporte-le-dmarrage-dolkiluoto-3-16-gw-%C3%A0-mai-2021/1128407, accessed 12 July 2020.

424 - TVO, "The best production year ever for Olkiluoto 1 plant unit", 2 January 2020, Press Release, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/thebestproductionyeareverforolkiluoto1plantunit.html, accessed 10 July 2020.

425 - Fortum, "A good production year 2019 at Fortum's Loviisa nuclear power plant - production record at unit 1", Press Release, 3 January 2020, see https://www.fortum.com/media/2020/01/good-production-year-2019-fortums-loviisa-nuclear-power-plant-production-record-unit-1, accessed 10 July 2020.

426 - TVO, "New operating license applied for Olkiluoto 1 and 2 plant units", 26 January 2017, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2017/hNRykwgEO.html, accessed 13 August 2020.

427 - TVO, "Finnish Government Approves Extension Of Operating Licences For OL1 And OL2 Plant Units", 20 September 2018, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2018/h7tODvf1I.html, accessed 13 August 2020.

428 - Fennovoima, "Rosatom acquired 34% of Fennovoima", Press Release, 27 March 2014.

429 - *WNN*, "Fennovoima changes spur progress with Hanhikivi project", 25 March 2020, see https://world-nuclear-news.org/Articles/Hanhikivi-project-progresses-following-Fennovoima, accessed 10 July 2020.

430 - *NEI*, Fennovoima issues progress report on Hanhikivi 26 March 2020, see https://www.neimagazine.com/news/newsfennovoima-issues-progress-report-on-hanhikivi-7839412, accessed 10 July 2020.

by Siemens,[431] was contracted to build the EPR at Olkiluoto (OL3) under a fixed-price, turnkey contract with the utility TVO. After the 2015 technical bankruptcy of AREVA Group, in which the cost overruns of Olkiluoto had played a large part, the majority shareholder, the French Government, decided to integrate the reactor-building division under "new-old name" Framatome into a subsidiary majority-owned by state utility EDF. However, EDF made it clear that it would not take over the billions of euros' liabilities linked to the costly Finnish AREVA adventure.[432] 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,[433] most of which was to cover the costs to AREVA of the OL3 project.

The OL3 project was financed essentially on the balance sheets of the Finland's leading firms and heavy energy users as well as a number of 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.

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.[434] 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 were considered by WNISR2019 as highly optimistic.[435]

In July 2019, TVO announced that it had once again delayed operations for OL3 by six months.[436] 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. "The re-baseline is now more exhaustive which we believe will make it possible to improve project performance",

431 - Siemens quit the consortium in March 2011 and announced in September 2011 that it was abandoning the nuclear sector entirely; see *WNN*, "Siemens quits the nuclear game", 19 September 2011, see https://world-nuclear-news.org/Articles/Siemens-quits-the-nuclear-game, accessed 13 August 2020.

432 - Jean-Michel Bezat, "EDF pose ses conditions au rachat des réacteurs d'Areva", *Le Monde*, 19 May 2015.

433 - 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 10 July 2020.

434 - 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 August 2020.

435 - *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 10 July 2020.

436 - 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 10 July 2020.

said Jouni Silvennoinen, TVO's director of the OL3 project.[437] By November 2019, the revised schedule for OL3 start had slipped a further six weeks, according to TVO.[438] The delays were reported to be due to final verification of the mechanical, electrical and the Instrumentation and Control (I&C) systems.

In December 2019, the AREVA-Siemens Consortium informed TVO that OL3 would be connected to the grid in November 2020 with electricity generation from March 2021.[439] Nuclear fuel loading was planned for June 2020. The delays were reported to be due to slow progression of system tests and shortcomings in spare-part deliveries.[440] Among other things in the tests of auxiliary diesel generators some faulty components were found.[441]

On 8 April 2020, TVO announced that it had applied to STUK (Säteilyturvakeskus), the Finnish radiation and nuclear safety regulator—for approval for fuel loading.[442] It was expected to take two months. At the same time, TVO revealed that as result of "significant amount of measures 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 project."[443] 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."[444]

The latest delay and uncertainty prompted a revision downwards of TVO's credit rating by S&P, with the timing and effect on OL3 commissioning "unclear" with expectations

> …that this will further increase project costs and postpone TVO's deleveraging, increasing the risk that the AREVA (not rated) is unable to maintain sufficient funds for related obligations, including the two-year guarantee period. The negative outlook reflects the risk that TVO's financial flexibility could diminish as a result of weaker counterparties or additional delays that could further increase already-high financial leverage.[445]

With the delay in fuel loading, and in a further sign of potential and additional financial risks for delay in OL3 commissioning, Fitch revised TVO's outlook from stable to negative, and

437 - Ibidem.

438 - TVO, "Plant supplier updates the schedule of OL3 project", 8 November 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2019/h0aOkf1fA.html, accessed 10 July 2020.

439 - TVO, "OL3 EPR's regular electricity generation starts in March 2021", 19 December 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprsregularelectricitygenerationstartsinmarch2021.html, accessed 10 July 2020.

440 - Ibidem.

441 - 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 10 July 2020.

442 - TVO, "TVO has submitted OL3 EPR unit nuclear fuel loading permission application", 8 April 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/tvohassubmittedol3eprunitnuclearfuelloadingpermissionapplication.html, accessed 10 July s2020.

443 - Ibidem.

444 - Ibidem.

445 - TVO, "Standard & Poor's has downgraded TVO's long term credit rating to BB", 15 April 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/standardpoorshasdowngradedtvoslongtermcreditratingtobb.html, accessed 10 July 2020.

stated that, "A significant delay could be negative for TVO's cash flow as the company has to service debt related to OL3".[446] The ratings agency, noted that

> There is a risk that the settlement agreement signed with the supplier consortium (AREVA NP, AREVA GmbH, Siemens AG (A/Stable) and AREVA Group's parent AREVA SA) in March 2018 would not protect TVO from financial impacts should the start of power production be delayed beyond June 2021, because the consortium has not yet assigned a new date for the fuel loading. After this date, TVO would not be entitled to penalty payments from the supplier consortium under the settlement agreement anymore.[447]

At the same time, weaker electricity prices, partially due to the COVID-19 pandemic, impact TVO. The Average Nord Pool system price in the first quarter 2020 was €15.4/MWh (US$16.9/MWh) compared with €46.8/MWh (US$52.5/MWh) for the same period in 2019. While Fitch reported that TVO's current nuclear production costs are about €20/MWh (US$21.7/MWh) and that this is estimated to increase to about €30/MWh (US$32.6/MWh) when OL3 starts commercial operation.[448] Nord Pool futures for 2021–2022 currently trade about €23–26/MWh (US$25.5–28.9/MWh) and Finnish area prices at slightly higher levels.

As reported by WNISR 2019 (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$515 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 would be reached in June 2021. With delays beyond June 2021, the agreement would not cover the financial impact on TVO. It was reported in April 2020, that AREVA was currently making arrangements in order to secure funding until the end of the project (including the guarantee period).[449]

Faulty Pressurizer Safety Relief Valves

On 9 July 2020, yet another potentially significant delay was announced in commissioning of OL3. STUK reported that defects in the pressurizer safety relief valves had been identified.[450] The valve on which the leak was found was mechanically damaged and after further checks similar cracks were detected in two of five other valves. STUK announced that the problem was serious and should be fully investigated before proceeding with nuclear fuel loading. The Sierion valves were disassembled, removed from OL3 and returned to the German manufacturer for detailed analysis.

446 - Fitch, "Fitch Revises Teollisuuden Voima Oyj's Outlook to Negative; Affirms at 'BBB-'", 20 April 2020, see https://www.fitchratings.com/research/corporate-finance/fitch-revises-teollisuuden-voima-oyj-outlook-to-negative-affirms-at-bbb-20-04-2020, accessed 10 July 2020.

447 - Ibidem.

448 - Ibidem.

449 - Ibidem; and TVO, "OL3 EPR's schedule work continues", 2 July 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprsscheduleworkcontinues.html, accessed 20 July 2020.

450 - onOZE, "Ponowne wstrzymanie budowy bloku elektrowni jadrowej Olkiluoto-3", 9 July 2020 (in Finnish), see https://onoze.pl/2020/07/09/ponowne-wstrzymanie-budowy-bloku-elektrowni-jadrowej-olkiluoto-3/, accessed 10 July 2020.

Pressurizer safety relief valves are F1A classified (must not fail) because it is necessary to reach a controlled state under Plant Condition Category (PCC) conditions. The EPR valves are required to perform vital functions in both routine and accident conditions.[451]

The safety relief valves type VS99 (Sierion) installed in OL3 were manufactured by the German company Sempell,[452] and their quality was confirmed in 2016–2017 by Erlangen Center owned by Framatome. As a result of the discovery, Sempell valves installed in the EPRs at Taishan-1 and -2 in China and Flamanville-3 in France are to be investigated. Sempell valves are also due to be installed in the Hinkley Point C EPR. As of early July 2020, the only disclosure from TVO was that "cracks were detected in the pilot valves of the pressurizer safety relief valves".[453]

OL3 Pressurizer Vibration

As reported by WNISR 2019 (see WNISR2019: Finland Focus), excessive vibration was detected in the pressurizer surge-line which contains high temperature and radioactive reactor coolant under high pressure. The vibrations were outside the permitted safety margin.[454] The Finnish safety regulator STUK, while reporting to the Government in February 2019 that operation of the OL3 would be safe, noted that before fuel loading could be authorized, technical solutions needed to be applied to suppress the pressurizer surge-line vibration of the primary circuit. STUK would "supervise the work and verify before the loading of fuel that the alteration works have been performed and the operability of the solution has been tested."[455] On 23 May 2019, TVO announced that it had "resolved" the surge-line vibrations.[456]

However, in TVO's July 2020 newsletter, it was stated that "all works have not progressed to plan and there has [have] been some technical problems. (…) Also, repair works related to the failed components of the emergency diesel generators and the vibration problems of the pressurizer surge line are still ongoing."[457]

OL3 was considered by the nuclear industry as a showcase for next-generation reactor technology with TVO and AREVA predicting 56 months to completion. However, WNISR envisaged over a decade ago that the project could lead to a crisis,[458] which has turned out to be

451 - UK-EPR, "Fundamental Safety Overview — Volume 2: Design and Safety — Chapter E: The Reactor Coolant System and Related Systems — Section E.4.5. Pressuriser Relief Line", 2007, see http://www.epr-reactor.co.uk/ssmod/liblocal/docs/V3/Volume%202%20-%20Design%20and%20Safety/2.E%20-%20The%20Reactor%20Coolant%20System%20and%20Related%20Systems/2.E.4/2.E.4.5%20-%20Pressuriser%20Relief%20Line%20-%20v2.pdf, accessed 10 July 2020.

452 - Emerson, "Sempell Nuclear Valves Secure leak-tight performance and 100% reliability for high pressure, high temperature applications", Sempell Nuclear Product Brochure, VCPBR-03316-EN, 2017.

453 - TVO, "TVO Newsletter—Respirator masks worn at OL3", 2 July 2020, see https://uutiset.tvo.fi/g/l/290020/0/0/2652/1012/7, accessed 10 July 2020.

454 - Lefteris Karagiannopoulos, "Exclusive: Safety problem found at Areva's Finnish reactor before start-up – regulator", *Reuters*, 22 February 2019, see https://www.reuters.com/article/us-finland-nuclear-safety-exclusive/exclusive-safety-problem-found-at-arevas-finnish-reactor-before-start-up-regulator-idUSKCN1QB27O, accessed 10 July 2020.

455 - STUK, "Radiation and Nuclear Safety Authority (STUK): Operating licence can be granted to Olkiluoto 3", Press Release, 25 February 2019, see https://www.stuk.fi/web/en/-/radiation-and-nuclear-safety-authority-stuk-operating-licence-can-be-granted-to-olkiluoto-3, accessed 10 July 2020.

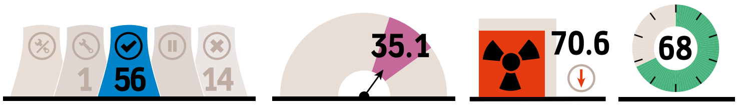
456 - *NW*, "Vibration damping system being installed at Olkiluoto-3 in Finland", 21 March 2019.

457 - TVO, "TVO Newsletter—Respirator masks worn at OL3", 2 July 2020, op. cit.

458 - WNISR, "The World Nuclear Industry Status Report 2009", August 2009, see https://www.worldnuclearreport.org/-2009-.html, accessed 9 June 2019; and Steve Thomas, "The EPR in Crisis", Public Services International Research Unit, Business School, University of Greenwich, London, November 2010, see https://gala.gre.ac.uk/id/eprint/4699/3/(ITEM_4699)_THOMAS_2010-11-E-EPR.pdf, accessed 4 June 2018.

rather accurate as its total construction time to commercial operation on the current schedule of May 2021, will be 204 months, 12 years behind schedule.

FRANCE FOCUS



The Energy and Climate Bill and the Multi Annual Energy Plan

On 9 November 2019, the French Energy and Climate Law entered into force.[459] It succeeds the 2015-Energy Transition Law. The legislation provides orientation, framework and rhetoric to the policy—e.g. the "ecological and climate urgency" makes its entry into the wording. A broader document, covering construction, transport, agriculture, industry, energy and waste, the "National Low-Carbon Strategy" ("Stratégie Nationale Bas-Carbone" or SNBC) toward the 2050-goal for carbon neutrality, was completed in March 2020.[460]

Specific energy policy targets and strategies to 2028 are defined in the Multi-Annual Energy Plan (Programmation Pluriannuelle de l'Énergie or PPE), a planning tool introduced in the 2015-Law. The PPE sets the priorities of action for public authorities concerning all forms of energy generation as well as energy efficiency. It also determines the near-term future of nuclear power in setting targets for installed capacity and therefore the potential closure of a number of reactors. On 23 April 2020, the French Government published the PPE, together with the SNBC, and it entered into force the following day.[461]

The new policy, while maintaining the target to reduce the nuclear share in the power production mix to 50 percent, moves it from 2025 to 2035. As of 2020, the renewable energy share is to reach 23 percent (21 percent in 2019, incl. hydro), and by 2030 "at least 33 percent" in final gross energy consumption and 40 percent in the electricity production.

At the same time, it raises the stakes on the phase-out of fossil fuels, increasing the 2030 target from –30 percent to –40 percent (baseline 1990) and thus reducing the overall 2050-greenhouse-gas emissions by a factor of more than six rather than four. The last coal-fired power plant is to be closed by 2022. However, this could be delayed as the Flamanville-3 EPR will not be in operation until then (see hereunder).

According to the Government model, achieving a reduction to 50 percent of the nuclear share in the electricity mix would lead to the closure of 12 reactors by 2035, in addition to the two oldest units at Fessenheim that were closed in spring 2020, and two to four additional units by 2028. Achieving the 2025 target would have meant the closure of over 20 reactors over a shorter time span.

459 - French Government, "LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat", *Journal Officiel de la* République Française, No. 0261, 9 November 2019 (in French), see https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000039355955&categorieLien=id, accessed 5 September 2020.

460 - MTES, "Stratégie nationale bas-carbone", Ministère de la Transition Écologique et Solidaire, March 2020 (in French), see https://www.ecologique-solidaire.gouv.fr/sites/default/files/2020-03-25_MTES_SNBC2.pdf, accessed 9 August 2020.

461 - French Government, "Décret n° 2020-456 du 21 avril 2020 relatif à la programmation pluriannuelle de l'énergie", *Journal Officiel de la République Française* n°0099, 23 April 2020. The same day, MTES released the full text of the SNBC and the PPE, see https://www.ecologique-solidaire.gouv.fr/publication-strategie-francaise-lenergie-et-climat-france-confirme-engagement-vers-societe-neutre-en, accessed 10 August 2020.

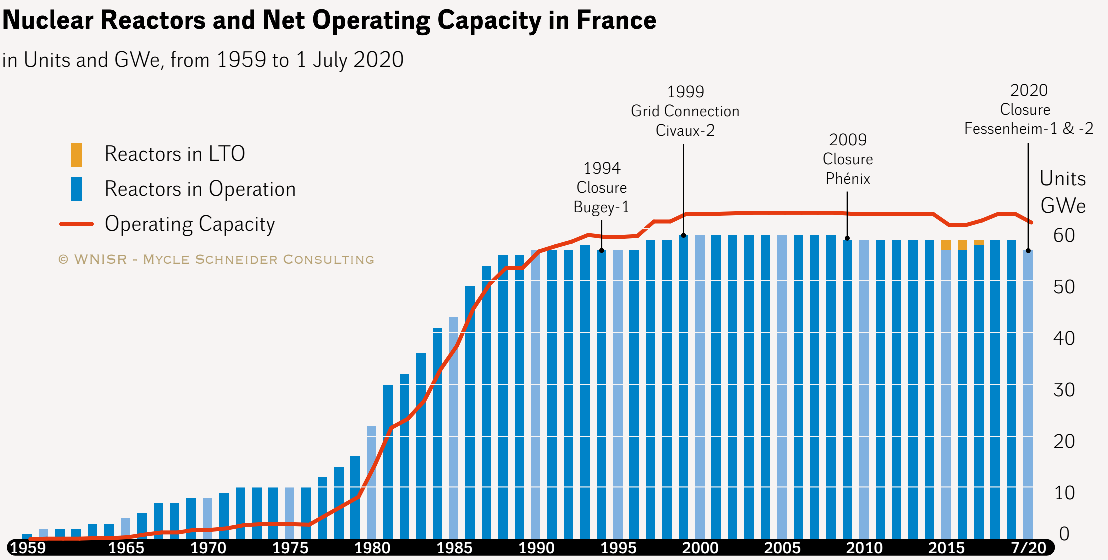
The PPE—citing jobs, reduction in natural uranium use and spent fuel generation, as well as "a better containment for the final waste"—stipulates that the "spent fuel reprocessing and recycling policy must be maintained".[462]

The incoming Minister of the Ecological Transition, Barbara Pompili, appointed during a reshuffle of the Government under President Emmanuel Macron in July 2020, an outspoken nuclear critic, will have to implement the PPE over the coming years. The nuclear establishment can count for continuity on a member of the Corps des Mines—a small group of elite technocrats from France's top-rated engineering schools that has elaborated, implemented and controlled the civil and military nuclear programs since the Second World War—who has been appointed to the position of energy and climate advisor in the Minister's Office.[463] Pompili will have to perform a difficult balancing act. Another nuclear critic in this position under President Macron from 2017 to 2018, Nicolas Hulot, complained about the "wall of lobbies" in the decision-making process (in various areas) and resigned two years ago.[464]

Two Reactor Closures, No Startup in Two Decades

Until the closure of the two oldest French units at Fessenheim in the spring of 2020, the French nuclear fleet had remained stable for 20 years, with the exception of the closure of the 250 MW fast breeder Phénix in 2009 (see Figure 32).

Figure 32 · Operating Fleet and Capacity in France (as of 1 July 2020)



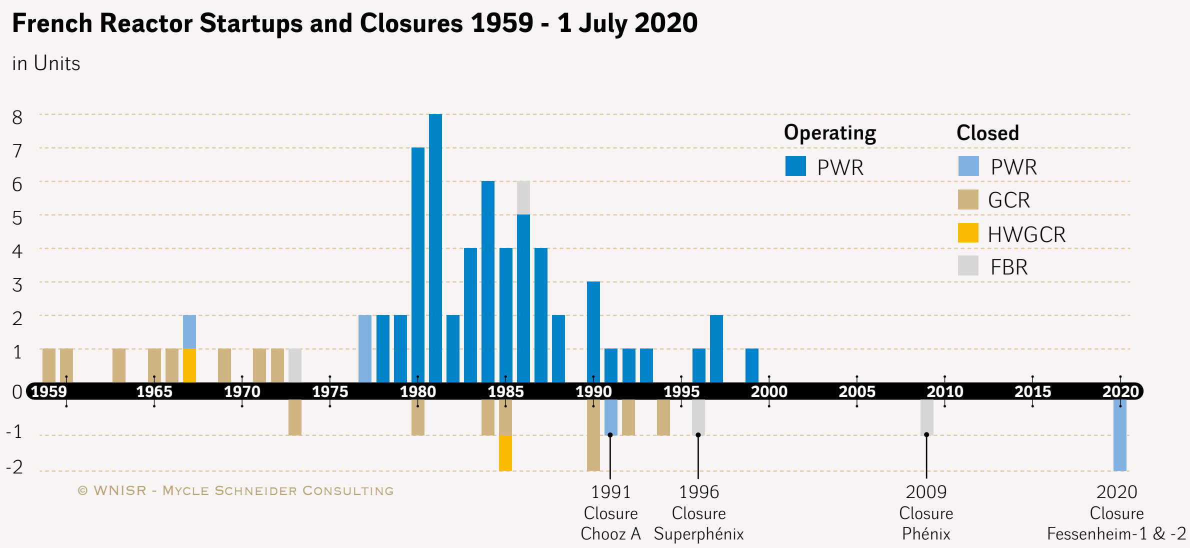
Source: WNISR, with IAEA-PRIS, 2020

462 - MTES, "French Strategy for Energy and Climate—Multi Annual Energy Plan—2019-2023—2024-2028", April 2019, pp.126–127, see https://www.ecologie.gouv.fr/programmations-pluriannuelles-lenergie-ppe, accessed 5 September 2020. The plutonium separation and use strategy is highly controversial but its discussion would be outside the scope of the WNISR. For information on reprocessing and plutonium, see work by the International Panel on Fissile Materials (IPFM) at fissilematerials.org.

463 - This position, as the equivalent positions in other relevant ministries and at the Prime Minister's and the President's offices, is traditionally held by the *Corps des Mines*, which allows for a long-term policy continuity.

464 - François Allard-Huver, "Nicolas Hulot, les lobbies et le macronisme", *Le Point*, 29 August 2018 (in French), see https://www.lepoint.fr/politique/nicolas-hulot-les-lobbies-et-le-macronisme-29-08-2018-2246655_20.php, accessed 17 August 2020.

Figure 33 · Startups and Closures in France



Source: WNISR, with IAEA-PRIS, 2020

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 the first generation natural-uranium gas-graphite reactors, two fast breeder reactors and a small prototype heavy water reactor (see Figure 33).

French Nuclear Power Performance Still Worsening

In 2019, 58 operating reactors[465] in France produced 379.5 TWh, a 3.5 percent drop over the previous year. It is the fourth year in a row that generation remained below 400 TWh, and 2020 is likely to turn out significantly worse, partially due to the COVID-19 crisis. In 2005, nuclear generation peaked at 431.2 TWh.

Nuclear plants provided 70.6 percent of the country's electricity, 1.1 percentage points less than in 2018, the lowest share since 1989. The share peaked in 2005 at 78.5 percent.

France's load factor dropped by 1.5 percentage points to 68.1 percent. The lifetime load factor remains constant below 70 percent (69.3 percent). There is not one French reactor in the top-100 ranked units in the world.

According to operator EDF:

> In 2019, generation performance was impacted by exceptional incidents and large-scale contingencies (totaling approximately 12 TWh), longer outage extensions than expected (totaling approximately 12 TWh) and environmental constraints (totaling approximately 4 TWh, including the Le Teil earthquake, accounting for 2.3 TWh).[466]

465 - All Pressurized Water Reactors (PWRs), 34 x 900 MW, 20 x 1300 MW, and 4 x 1400 MW.

466 - EDF, "Universal Registration Document 2019— Annual Financial Report", (formerly "The Reference Document"), filed 13 March 2020, see https://www.edf.fr/en/the-edf-group/dedicated-sections/investors-shareholders/reference-documents, accessed 6 September 2020.

Environmental constraints—other than the Le Teil earthquake that led to the provisional shutdown of the four Cruas reactors—refer to operating restrictions for several nuclear plants because of lack of cooling water or excess water temperatures. The heat wave in the summer of 2019 led to the closure or output reduction of several reactors, including the two Golfech units and the two Saint-Alban units. Remarkably, in September 2019, Chooz-2 and Cattenom-4 were shut down, while Bugey-2 and -3 as well as Chooz-1 and Cattenom-2 had to reduce their generation for lack of cooling water. Droughts that can last for weeks impact availability significantly more than heat waves that rarely exceed a few days (yet), concludes an independent analysis.[467]

Nuclear Unavailability Review 2019

The analysis of the unavailability of French nuclear reactors in 2019 shows:

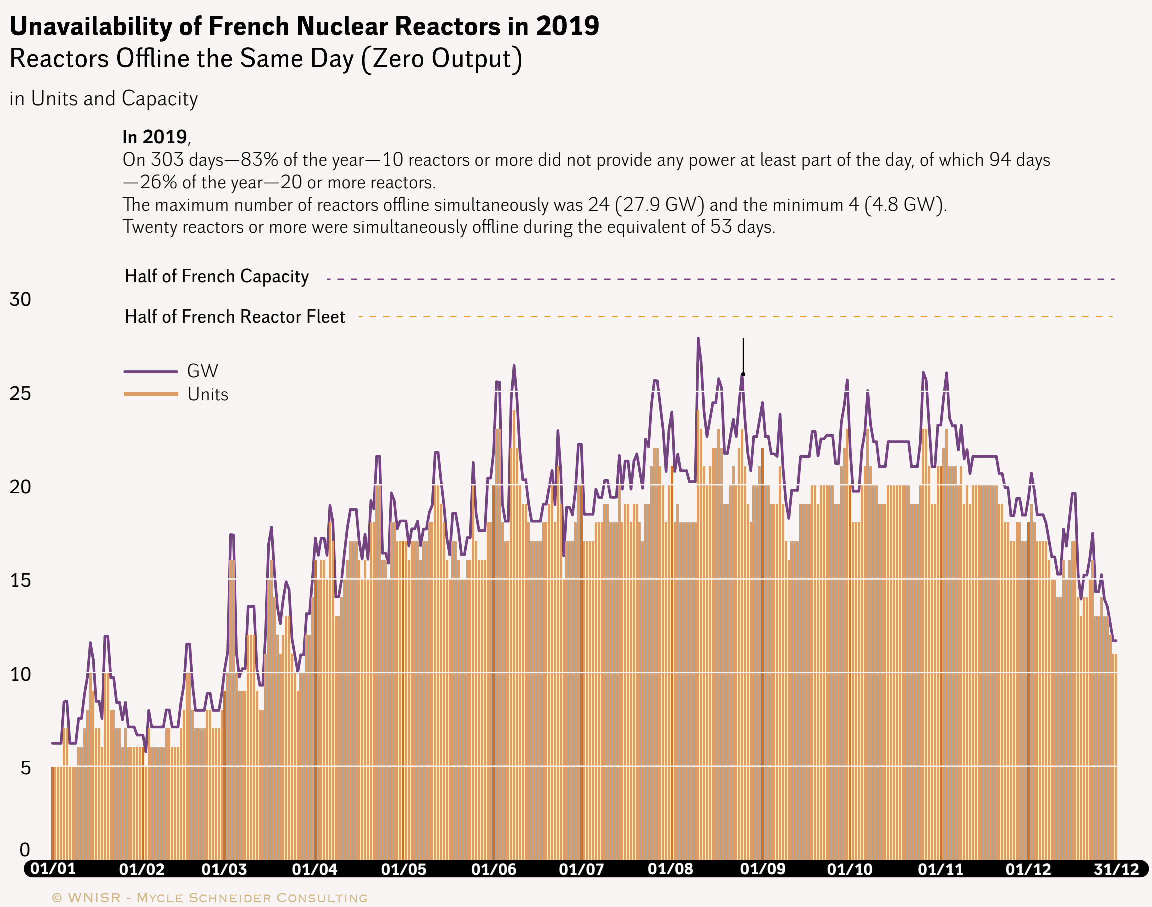
- At least four reactors (4.8 GW) were down (zero capacity) simultaneously at any day of the year.
- A maximum of 24 (27.9 GW) of the 58 units were down at the same time.
- On 303 days (83 percent of the year), at least 10 units were down during the same day.
- On 94 days (26 percent of the year), 20 or more units were shut down for at least part of the day, cumulating 53 outage days in total.

The total duration of zero output of the French reactor fleet reached 5,580 reactor-days in 2019 (up 500 days or 10 percent), an average of 96.2 days per reactor or an outage ratio of over a quarter of the time, not including load following or other operational situations with reduced but above zero output e.g. as during the heat wave and drought. All 58 reactors were subject to outages ranging from 5–356 days (see Figure 34 and Figure 35).

EDF's declaration of "planned" vs. "forced" outages is grossly misleading. According to that classification, in 2019, 13 reactors did not have any "forced" outage, at seven units they lasted less than one day, and at 30 between one and ten days, just eight reactors fall in the range between 11 and 48 days of "forced" outage.

467 - Thibault Laconde, "Effet de la météo sur la disponibilité du parc nucléaire français : quelle réalité ?", *Energie & Développement*, 28 July 2020 (in French), see http://energie-developpement.blogspot.com/2020/07/meteo-climat-disponibilite-nucleaire.html, accessed 11 August 2020.

Figure 34 · Reactor Outages in France in 2019 (in number of units and GWe)

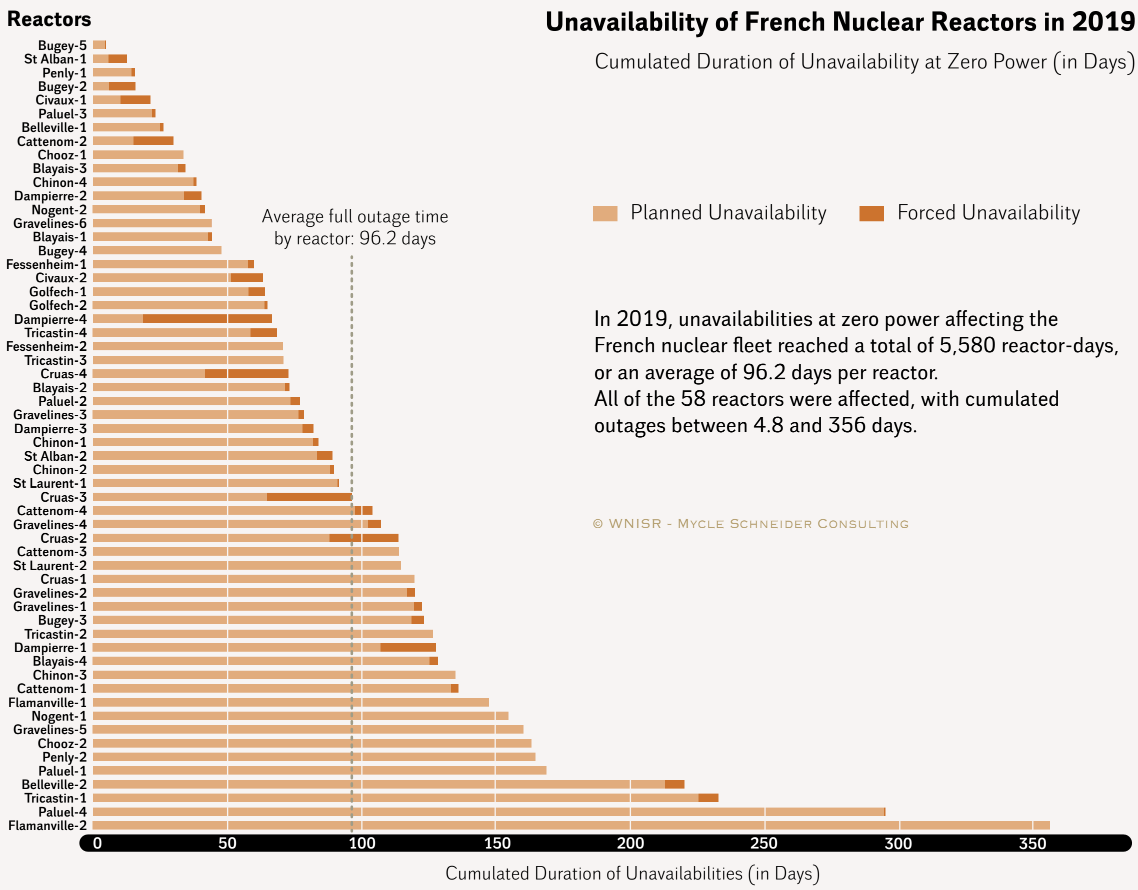


Sources: RTE, 2020 and EDF, "List of outages", 2020.[468]

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.

468 - EDF, "List of outages", see https://www.edf.fr/en/the-edf-group/who-we-are/activities/optimisation-and-trading/list-of-outages-and-messages/list-of-outages, last accessed August 2020.

Figure 35 · Forced and Planned Unavailability of Nuclear Reactors in France in 2019



Sources: Compiled by WNISR, with RTE, 2019–2020.

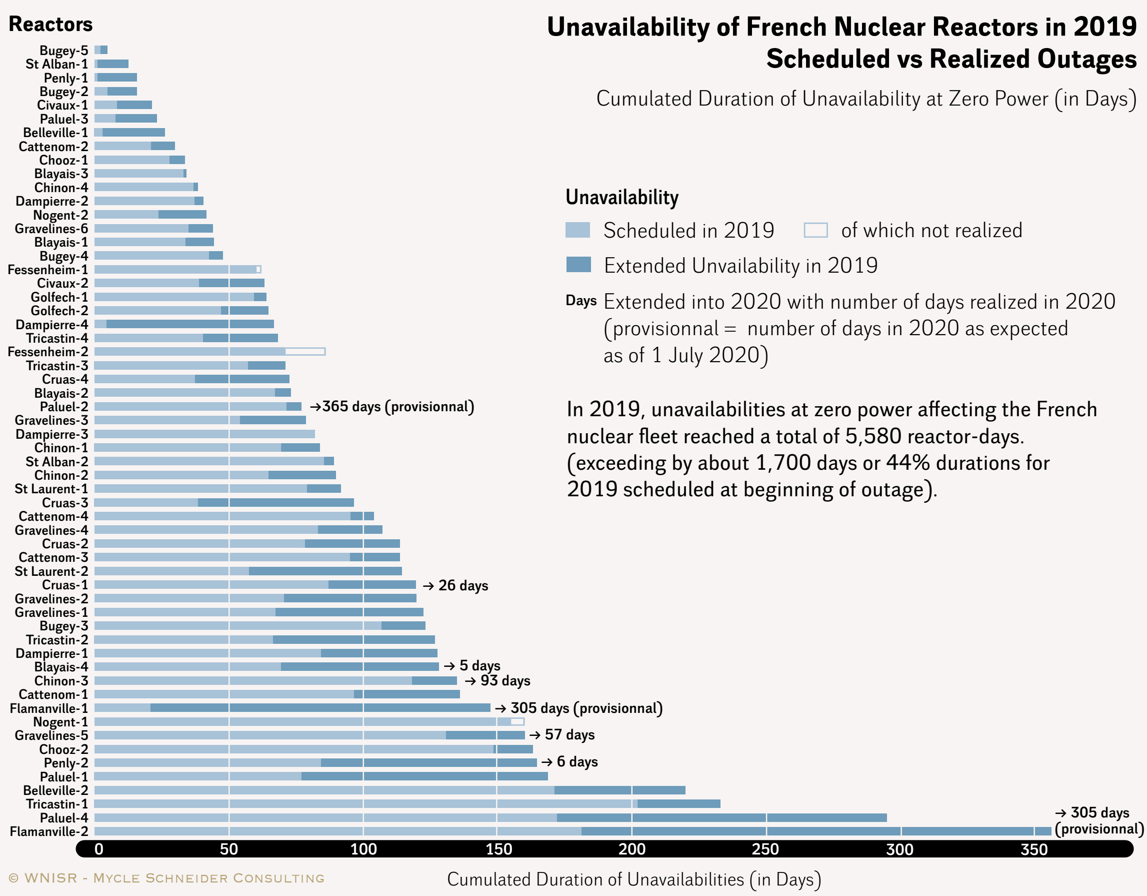
Notes

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.

EDF considers an outage as planned whatever the number of extensions and whatever its total duration. In fact, WNISR analysis shows that only one unit (Dampierre-3) restarted as planned after a long outage of 82 days. Outages were shortened at the two Fessenheim reactors, which were closed in the first half of 2020, and at Nogent-1. All other outages at the 54 remaining units were extended beyond planned grid reconnection dates. The unplanned delays ranged from 1.3 to 175 days. The additional unavailability added up to 1,705 days, an increase of 44 percent over the expected outage duration. (See Figure 36).

Figure 36 · Scheduled vs. Realized Unavailability of Nuclear Reactors in France in 2019



Sources: Compiled by WNISR, with RTE data, 2018–2020.

Notes

This figure shows the reactor outage durations for 2019 as scheduled at outage start vs. actual outage duration over the year, for both planned and forced unavailability. In case a reactor was shut down in 2018 and due to be back on-line prior to 31 December 2018, the outage duration in 2019 is entirely considered as extended unavailability. Extended duration into 2020 are signaled, but not represented on the graph.

> *"the outage extensions experienced in 2019 were caused in equal measure by maintenance and operational quality issues, technical failures and project management deficiencies"*

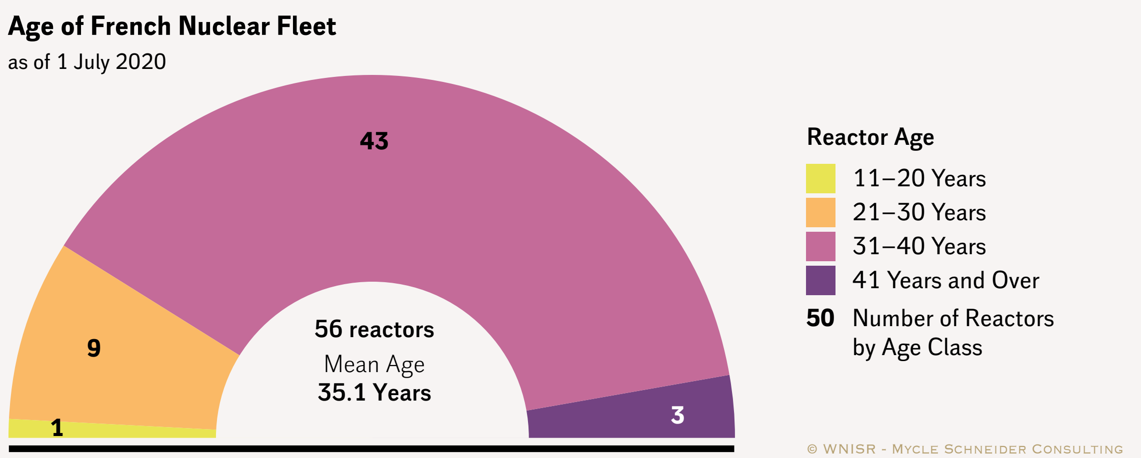
These numbers are covering the year 2019 only and do not take into account outages that reached into 2020, some of which are still ongoing as of mid-year. The Flamanville site is the worst performer, with Unit 1 cumulating 127 days and Unit 2 even 175 days of unscheduled outage extensions as of the end of 2019. As of mid-2020, the two units were still unavailable and are now expected to remain offline until October 2020, adding another 305 days to each of the reactor's unplanned outage extension. EDF continues to label the entire outage duration for both units as "planned", a policy that does not help the public and decision-makers to understand the real nature of plant management and performance by the largest nuclear operator in the world.

According to EDF, "the outage extensions experienced in 2019 were caused in equal measure by maintenance and operational quality issues, technical failures and project management deficiencies".[469]

Lifetime Extension, ASN and the Fourth Decennial Reviews

By mid-2020, the average age of France's 56 power reactors exceeded for the first time 35 years (see Figure 37). Lifetime extension beyond 40 years—46 operating units are now over 31 years old—would require significant additional upgrades. Also, relicensing will be subject to public enquiries reactor by reactor.

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



Sources: WNISR, with IAEA-PRIS, 2020

Operating costs have increased substantially over the past years. The bad performance with outage durations systematically exceeding planned timeframes is particularly costly. EDF's net financial debt increased by €8 billion (US$9 billion) in 2019 and grew by another €1 billion (US$1.1 billion) in the first half of 2020, mainly due to the COVID-19 effect, to a total of €42 billion (US$47 billion).[470] Until 2022, the COVID-19 effects might add a total of €5–10 billion (US$6–12 billion) to the company's debt burden and increase the pressure for further cost savings.[471]

Investments for lifetime extensions will need to be balanced against the excessive nuclear share in the power mix, the stagnating or decreasing electricity consumption in France—it has been roughly stable for the past decade—and in the European Union (EU) as a whole, the shrinking client base due to successful competitors, and the energy efficiency and renewable energy production targets set at both the EU and the French levels.

469 - EDF, "Universal Registration Document 2019— Annual Financial Report", filed 13 March 2020, op. cit.

470 - EDF, "2020 Half-Year Results", Press Release, 30 July 2020, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/2020-half-year-results, accessed 6 September 2020.

471 - *Le Monde*, "'Mimosa', le nouveau plan d'économies d'EDF", 7 July 2020.

At the beginning of 2018, EDF claimed its power generating costs for existing reactors would be €32/MWh (US$38/MWh)—including nuclear operating and maintenance costs (€22/MWh or US$$_{2018}$26/MWh including fuel at €5/MWh – US$$_{2018}$6/MWh) and all anticipated upgrading costs for plant life extension to 50 years (10 €/MWh or US$$_{2018}$12/MWh)—and would remain more economic than "any new alternative".[472]

However, there are serious questions about these numbers. Michèle Pappalardo, former senior representative of the Court of Accounts, remarked during the National Assembly's Inquiry-Committee hearings that EDF's calculation stopped mid-way in 2025, and recalled that the Court had calculated a total cost of €100 billion (US$117 billion) for the period 2014–2030.[473]

These estimates were based on the situation in early 2018, but EDF's performance in 2018-19 significantly deteriorated with unprecedented outage extensions, thus low production levels in a low-price, low-consumption market environment. The items had not been factored into the 2018-cost calculations. The COVID-19 crisis led to a further degradation of the situation, which will have repercussions including in 2021-2022 (see also Nuclear Power in the Age of COVID-19).

EDF will likely seek lifetime extension beyond the 4th Decennial Safety Review (VD4) for most if not all of its remaining reactors. This is in line with the Government's Multi-Annual Energy Plan (PPE), which plans for no further reactor closures until 2023 (the current presidential term runs until spring 2022) and only a limited number in the following years. This program will be limited to 900 Mwe reactors, the oldest segment of the French nuclear fleet. The first reactor to undergo the VD4 was Tricastin-1 in 2019, furthermore were scheduled Bugey-2 and -4 in 2020, and Tricastin-2, Dampierre-1, Bugey-5 and Gravelines-1 in 2021. Of course, COVID-19 came by in the meantime.

While the President of 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.[474] 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 the 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 by the recent outage history, 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.[475]

472 - EDF, "Le parc nucléaire en exploitation en France : Exploitation, maintenance et Grand Carénage", 11 January 2018.

473 - Barbara Pompili, "Rapport d'enquête sur la sûreté et la sécurité des installations nucléaires—N° 1122 tome II", 28 June 2018 (in French), see http://www.assemblee-nationale.fr/15/rap-enq/r1122-tII.asp, accessed 19 July 2018.

474 - Bernard Doroszsuk, Hearing at the National Assembly, 28 May 2020, see http://videos.senat.fr/video.1628244_5ecf547f8a96f.audition-pleniere---autorite-de-surete-nucleaire?timecode=2963962, accessed 13 August 2020.

475 - 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.

Detailed generic requirements for plant life extension have not been issued yet by the Nuclear Safety Authority (ASN). Originally, these requirements were to be issued in 2016 but their release has been postponed a number of times, due to the need for extended and often unprecedented technical discussions. The general objective of ASN has been to bring the reactors "as close as possible" to the safety level required in new reactor designs, such as the EPR under construction in Flamanville. ASN notes in its 2019-Annual Report:

> The safety reassessment of these reactors and the resulting improvements must be carried out by comparison with the new-generation reactors, such as the EPR, the design of which meets significantly reinforced safety requirements.[476]

This is strikingly different from most other countries, where safety authorities merely request to maintain a given safety level. ASN plans to issue its generic order by the end of 2020, which is somewhat surprising as this is now one year after Tricastin-1 had completed the procedure.

ASN made it clear that while EDF's suggested backfitting and upgrading program improves safety, it is not there yet:

> However, at this stage of the examination, ASN considers that these modifications alone are unable to meet all the targets set. In the absence of any additional proposals from the licensee during the course of 2020, ASN will prescribe additional modifications.[477]

And then there is the public:

> ASN will also consult the public at the end of 2020 on the position it is to adopt on the generic phase of the periodic safety review. Pursuant to the law, a public inquiry will then be held, reactor by reactor, after submission of the periodic safety review conclusions report for each of them.[478]

The Ongoing Flamanville-3 EPR Saga

EDF has overestimated its project-management competence and organized itself only very late to face the issue.

Court of Accounts, July 2020[479]

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.

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 similar to those at the Olkiluoto (OL3) project in Finland, which started two-and-a-half years earlier. These problems never stopped and in April 2018, it was discovered that the main welds in the secondary steam system did not conform with the

476 - ASN, "ASN Report on the state of nuclear safety and radiation protection in France in 2019", 15 July 2020, 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-2019, accessed 17 August 2020.

477 - Ibidem.

478 - Ibidem.

479 - Cour des Comptes, "La filière EPR", 9 July 2020.

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."[480] In fact, the delay will be several years, and the startup of FL3 is not expected before the end of 2022 at the earliest. However, that was the projection prior to the COVID-19 crisis and additional delays are likely.

In a letter of 19 June 2019, ASN informed EDF that "in the light of the numerous deviations in the production of the Flamanville EPR penetration welds, they would have to be repaired"[481]. ASN pointed out in the letter, signed by the Chairman:

> **ASN considers that, given the number and nature of the deviations affecting these welds, their break can no longer be considered as highly improbable and that a break preclusion approach can no longer be applied to them.** [Bold font in the original.][482]

EDF would like to use "remotely controlled welding robots, designed to conduct high-precision operations within the pipework in question". However, this technology has been developed for the fleet in operation and has not been qualified yet for reworking penetration welds. EDF aims for this scenario to be qualified and approved by ASN "no later than the end of 2020". A second scenario, involving extraction and upgrading in auxiliary backup buildings, is presently being kept as an alternative solution.[483]

In July 2018, the owner-builder stated had adjusted the Flamanville EPR schedule and construction costs with the loading of nuclear fuel scheduled for the 4th quarter in 2019 and the target construction costs "revised from €10.5 billion [US$12.3 billion] to €10.9 billion [US$12.7 billion]".[484] EDF revised its position in July 2019 and announced that, concerning the FL3 steam line repair work, it "expects to communicate the schedule and cost implications of the selected scenario in the next few months", already certain that "commissioning cannot be expected before the end of 2022".[485] One year later, in July 2020, EDF stated that fuel loading would now be delayed to "late 2022" and construction costs re-evaluated at €12.4 billion (US$14.7 billion), an increase of €1.5 billion (US$1.8 bllion) over the previous estimate.[486]

480 - EDF, "Quality deviations on certain welds of the secondary circuit at the Flamanville EPR: the investigation continues", 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.

481 - ASN, "Deviations on the Flamanville EPR steam lines: the eight penetration welds will have to be repaired", Information Notice, 20 June 2019, see http://www.french-nuclear-safety.fr/Information/News-releases/Deviations-on-the-Flamanville-EPR-steam-lines-the-eight-penetration-welds-will-have-to-be-repaired, accessed 20 June 2019.

482 - ASN, "Letter to the Chairman of EDF", 19 June 2019, see http://www.french-nuclear-safety.fr/Media/Files/letter-CODEP-CLG-2019-027253-UK-ASN-EDF-VVP-EPR, accessed 28 July 2019.

483 - EDF, "Annual Financial Report 2019 – Universal Registration Document", March 2020, op.cit.

484 - EDF, "Welds in the main secondary system of the Flamanville EPR: EDF sets up corrective actions and adjusts schedule and target construction costs", 25 July 2018, see https://www.edf.fr/en/edf/welds-in-the-main-secondary-system-of-the-flamanville-epr-edf-sets-up-corrective-actions-and-adjusts-schedule-and-target-construction-costs, accessed 25 July 2018.

485 - EDF, "Half-Year Results 2019", 25 July 2019.

486 - EDF, "Annual Financial Report 2019 – Universal Registration Document", March 2020, op.cit.

The latest delays raised another legal problem. The construction license had already been extended by three years in 2017 to 10 April 2020.[487] On 23 July 2019, EDF filed a new application to amend the construction license.[488] On 25 March 2020, the Government passed a decree extending the construction license by another four years.[489] Whether this will be sufficient remains to be seen. FL3 is currently over a decade behind schedule.

A Damning Court of Accounts Report

In July 2020, the French Court of Accounts (Cour des Comptes) released a damning report about the EPR.[490] The 148-page report (including the traditional responses by the Government and companies involved) is not only an exceptional documentation of the failures and mishaps of project management, engineering and huge financial consequences, it is foremost an unprecedented illustration of the total absence of state oversight and complacent, if not negligent, commercial agreements with EDF's contractors for the construction of the Flamanville-3 EPR. See citations below (translation by WNISR).

The Court reminds the reader that the decision to build Flamanville-3 had been taken in June 2004 on the basis of an overnight cost estimate of $€_{2001}$2.8 billion ($€_{2015}$3.5 billion which translates to $US\$_{2001}$2.5 billion or $US\$_{2015}$3.8 billion) and a construction time of 57 months (or 67 months between the concreting of the basemat of the reactor building and commercial operation). The reactor was supposed to generate power at $€_{2001}$36.2–41.1/MWh ($€_{2015}$47–53/MWh). Since 2008, EDF has not publicly released any update to this cost range. In 2012, the Court of Accounts estimated the generation cost range at €70–90/MWh ($\$_{2012}$93–120/MWh), stating however, it would not validate any figure prior to a minimum of operating experience and an examination of the accounts.

In addition to the overnight construction costs, as of December 2019, EDF indicated more than €4.2 billion ($US\$_{2019}$4.6 billion) for various cost items, including €3 billion ($US\$_{2019}$3.3 billion) of financial costs. On 1 July 2023, latest provisional date for the startup of the reactor, these additional costs could therefore reach $€_{2015}$6.7 billion ($US\$_{2015}$7.4 billion). The latest construction cost estimate given by EDF of $€_{2015}$12.4 billion would represent about two thirds of the total thus estimated at $€_{2015}$19.1 billion ($US\$_{2020}$20 billion).

On the basis of the updated cost estimates, the Court states that the Flamanville-3 electricity could possibly be generated at $€_{2015}$110–120/MWh, a cost range similar to the price range negotiated for the Hinkley Point C project in the U.K.

487 - Ministry of the Environment, Energy and the Sea, in charge of International Relations on Climate, "Décret n° 2017-379 du 23 mars 2017 modifiant le décret n° 2007-534 du 10 avril 2007 autorisant la création de l'installation nucléaire de base dénommée Flamanville 3, comportant un réacteur nucléaire de type EPR, sur le site de Flamanville (Manche)", 24 March 2017 (in French), see https://www.legifrance.gouv.fr/affichTexte.do;jsessionid=0385C6ECDD66D0F6D6896702526A28A5.tpdila22v_2?cidTexte=JORFTEXT000034264985&dateTexte=&oldAction=rechJO&categorieLien=id&idJO=JORFCONT000034264920, accessed 28 July 2019.

488 - EDF, "Half-Year Results 2019", 25 July 2019.

489 - *JORF*, "Décret no 2020-336 du 25 mars 2020 modifiant le décret no 2007-534 du 10 avril 2007 autorisant la création de l'installation nucléaire de base dénommée Flamanville 3, comportant un réacteur nucléaire de type EPR, sur le site de Flamanville (Manche)", *Journal Officiel de la République Française*, 27 March 2020.

490 - Cour des Comptes, "La filière EPR", 9 July 2020, see https://www.ccomptes.fr/fr/publications/la-filiere-epr. All quotes in this section from this document, unless otherwise noted.

All of these numbers do not take into account the COVID-19 effect, and EDF warned that the construction interruption at the Flamanville EPR "could result in further delays and additional costs".[491]

Quotes from the Court of Accounts (Cour des Comptes) Report on the EPR[492]

On the client-supplier relationship

The mechanisms serving to apply a risk matrix common to client and supplier respecting the rules of public orders have not been implemented. (...)

On the absence of state control

Not one of the notes produced by the National Holdings Agency [APE]493 between 2004 and 2019 mentions concern or questioning of the APE about the project, its cost, its successive escalations and the risks that it represented for EDF and therefore by consequence for the State. The minutes of EDF board meetings mention only one intervention by the manager of the State participations in this project, concerning the first amendment to the contract with Bouygues. After that, successive cost escalations at project completion did not even trigger a single reaction of APE representatives on the EDF Board anymore. The shareholder appears like a spectator, including on the issues of quality defaults that he seems to know of only by the media.

The notes of the General Directorate for Energy[494] (...) do not contain any more alarm signals to the ministers, or critical analyses of the EDF's management of the Flamanville-3 construction site. Questioned about the basis for its favorable opinion on the construction of the EPR, (...) it relied on the technical and economic evaluation of the public company. The same way, in a note dated 9 December 2008, the General Director for Energy and Climate took over the construction perspectives for the industrial companies, without taking any distance.

For its part, the General Directorate of the Treasury[495] has indicated to the Court not to have elaborated any assessment of the economic value of the project.

In this context, it has not been established that the supervisory administrations carry out the task of technical instruction sufficiently in-depth to enlighten the decision-makers.

491 - EDF, "2020 Half-Year Results", Press Release, 30 July 2020.

492 - Trasnlation by WNISR; Cour des Comptes, "La filière EPR", 9 July 2020, see https://www.ccomptes.fr/fr/publications/la-filiere-epr, accessed 15 August 2020.

493 - The "Agence des Participations de l'État" or APE was created in 2004 and manages the government shares in about 70 major companies generally majority state owned.

494 - Originally part of the Industry Ministry, now as General Directorate for Energy and Climate (DGEC) part of the Ministry for the Ecological Transition, in charge of the oversight of the national energy companies and the nuclear sector.

495 - Part of the Ministry of the Economy and Finance.

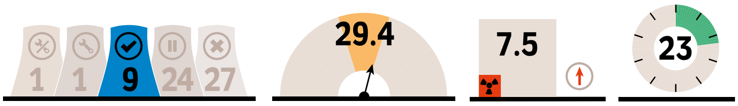
On future nuclear construction projects

The situation of EDF, a listed company and already indebted, is incompatible with the massive investment needs the company would have to face in case of the deployment of new reactors.

Nuclear projects present high risks and an insufficient profitability in order to attract private investors under these conditions.

EDF cannot finance alone anymore the construction of new reactors. Thus, this construction will not be done without public support in one form or another. The burden, which in this case would be transferred to the consumer and/or to the taxpayer would only be acceptable if nuclear energy, with respect to the national objectives in the fight against climate change and security of supply, is sufficiently competitive compared to other electricity-production modes, renewables in particular.

JAPAN FOCUS



Japan's nuclear industry has had a mixed year, with nine reactors operating through most of 2019, leading to the highest electricity generation since 2011. However, in 2020, reactor operations have been disrupted due to extended and unplanned outages as well as a further damaging court ruling.

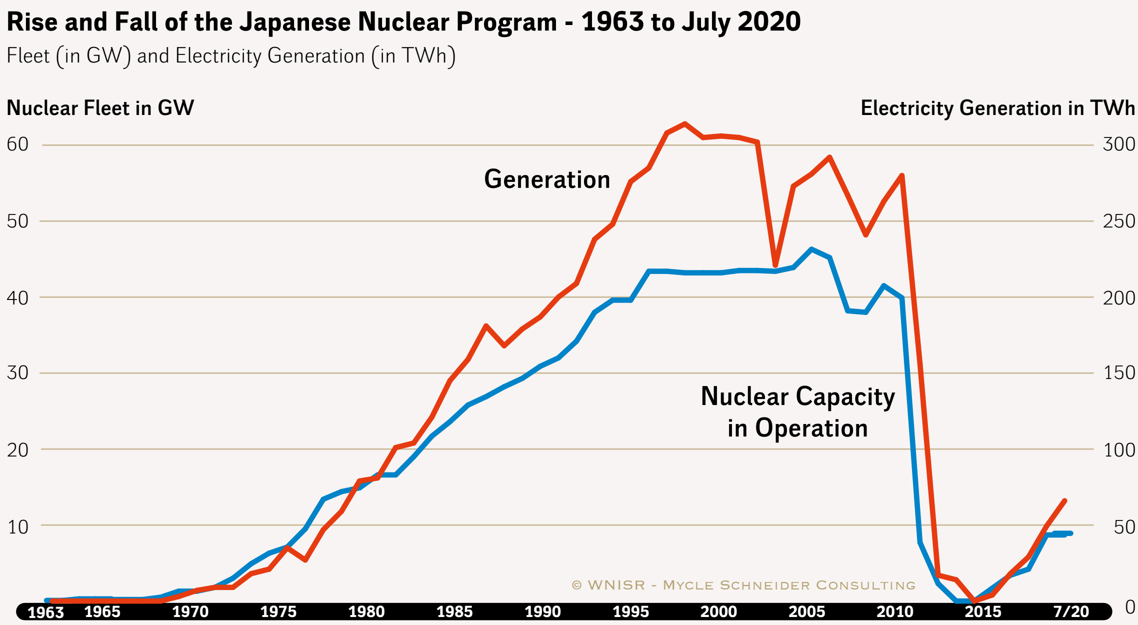
As of 1 July 2020, four of the nine operating reactors were shut down, two due to the failure to complete construction work related to terrorism counter measures, one due to unresolved steam-generator tube-damage, and one due to a court ruling. With an additional reactor (Takahama-4) due to be shut down in October 2020, again due to failure to complete counterterrorism upgrading, Japan's nuclear generation in 2020 is expected to decline by half.

During the past year Japan's largest nuclear utility (in terms of number of remaining operational reactors), Kansai Electric Power Company (KEPCO), was at the center of a bribery and corruption scandal that has prompted reminders of the 'nuclear village' culture that became wider known in the aftermath of 3/11. As in 2018, no additional reactors restarted in the year to 1 July 2020 under the revised Nuclear Regulatory Authority's (NRA) safety guidelines. Restart dates for three reactors in Long-Term Outage (LTO) have already been pushed back into late 2020 and 2021, but it remains doubtful that they will successfully meet these dates.

Lawsuits against nuclear plants have continued to destabilize reactor operations in Japan, the most recent being in January 2020, which has forced the extended shutdown of the PWR Ikata-3. This is the second time in the past 25 months that the reactor owner, Shikoku Electric Power Company, was forced into extended shutdown of the reactor, after an unprecedented high court ruling in December 2017 (see WNISR2018).

No additional reactors have been declared for closure during the past year, thus the total remains unchanged at 21 reactors (including the ten at Fukushima Daiichi & Daini). This means that as of 1 July 2020, 24 reactors remain in LTO since none of these have generated electricity during recent years. WNISR has considered for years that the four reactors at Fukushima Daini will never restart. (See Figure 39 and Annex 3 for a detailed overview of the Japanese Reactor Program).

Figure 38 · Rise and Fall of the Japanese Nuclear Program



Sources: WNISR, with IAEA-PRIS, 2020

In 2019, according to IAEA-PRIS, nuclear power in Japan produced 65.6 TWh contributing 7.5 percent of the nation's annual output compared to 49.3 TWh and 6.2 percent in 2018. This is the largest share of nuclear generated electricity in Japan since 2011 (18 percent), compared with 29 percent in 2010 and the historic high of 36 percent in 1998. According to the Ministry of Economy, Trade and Industry (METI), solar PV generation in 2019 was 71.5 TWh, up 12.2 percent, outpacing nuclear production.[496]

The reduction in electricity generation from nuclear power in 2020 due to extended shutdowns, coincides with a significant decline in demand and wholesale prices due to the COVID-19 pandemic.[497] As reported by *Reuters*, day-ahead prices on the Japan Electric Power Exchange (JEPX) dropped as low as ¥0.01 (US$c0.01) per kilowatt hour (kWh)—virtually free power— in February 2020.

496 - METI/ANRE, "Monthly Report on Electricity Statistics", quoted by Renewable Energy Institute, "Energy Statistics", 30 July 2020 (in Japanese), see https://www.renewable-ei.org/statistics/resources/, accessed 16 August 2020.

497 - Aaron Sheldrick, "Japan power prices hit zero as coronavirus hammers industrial activity", *Reuters*, 13 May 2020, see https://www.reuters.com/article/us-health-coronavirus-japan-electricity/japan-power-prices-hit-zero-as-coronavirus-hammers-industrial-activity-idUSKBN22P0PA, accessed 19 May 2020.

At the same time, the 1 April 2020 saw grid unbundling, whereby utilities were required to separate their transmission and distribution (T&D) from their power generation and supply businesses. Considered essential to increasing competition within electricity markets, Japanese utilities have devised methods to limit the negative impact of the measures. However, as *Moody's* noted, earnings for utilities have become more volatile while customers bases are shrinking, and that ongoing deregulation is credit negative for the electric utilities in Japan.[498] Additional debt has accumulated due to the costs of nuclear safety measures under prolonged nuclear reactor shutdowns. As WNISR2019 reported, the industry has been working to counter these unfavorable electricity market conditions. If implemented, the counter measures will provide significant financial incentives for extending reactor operations beyond 40 years. In particular, a capacity market is now planned to operate in Japan from 2021.[499] The principal beneficiaries of this will be the utilities operating nuclear power and coal plants.[500]

As in previous years, a consistent majority of Japanese citizens, when polled, continue to oppose the sustained reliance on nuclear power, support its early phase-out, and remain opposed to the restart of reactors.[501]

Kansai Electric Bribery Scandal

The past year revealed a decades-lasting bribery and corruption scandal in Fukui Prefecture in western Japan that extended from local contractors, a former Takahama mayor, local prefectural officials, a chapter of the ruling Liberal Democratic Party (LDP) and executives of Kansai Electric Power Company (KEPCO), including the President.[502] Long considered the nuclear peninsula of Japan, Fukui Prefecture hosts 11 KEPCO reactors, four of which are slated for decommissioning. The disclosure of kickbacks to utility executives and officials raised considerable public attention in the Kansai region and wider Japan. Although considered to have implications for restart approval for three of the company's reactors, the PWR Mihama-3, Takahama-1 and -2, which were scheduled for operation between 2020 and 2021, the outcome remains unclear given how embedded local support for nuclear power remains at elected official level.

In September 2019 it was disclosed that the Kanazawa Bureau of the National Tax Agency (NTA) review of the accounts of Yoshida Kaihatsu a civil engineering and construction company based in Takahama showed the transfer of large sums of money exceeding ¥300 million

498 - Moody's, "Japanese utilities' strategies increasingly drive credit profiles as industry deregulates", 6 February 2020, see https://www.moodys.com/research/Moodys-Japanese-utilities-strategies-increasingly-drive-credit-profiles-as-industry--PBC_1213425; and *AsianPower*, "Japan utilities' deregulation puts heat on earnings", 12 February 2020, see https://asian-power.com/power-utility/news/japan-utilities-deregulation-puts-heat-earnings, both accessed 19 May 2020.

499 - Nobuyuki Yamaguchi, Nahako Totsuka et al, "Scenario analysis of balancing capacity market based on unit commitment", E3S Web of Conferences 152, University of Tokyo, PEEE 2019, 2020, see https://www.e3s-conferences.org/articles/e3sconf/pdf/2020/12/e3sconf_peee2020_02003.pdf, accessed 19 May 2020.

500 - Matsukubo Hajime, "The Capacity Market: An overview and issues", Citizens Nuclear Information Center, 3 June 2019, see https://cnic.jp/english/?p=4435, accessed 19 May 2020.

501 - Kaoru Ohno, "JAIF Releases Results of Fact-Finding Survey of Japanese Nuclear Industry for Fiscal 2018", JAIF, 27 November 2019, see https://www.jaif.or.jp/en/jaif-releases-results-of-fact-finding-survey-of-japanese-nuclear-industry-for-fiscal-2018/, accessed 29 May 2020.

502 - *Japan Times*, "LDP chapter led by ex-defense chief Inada got donations from firm with ties to man at heart of Kepco scandal", 5 October 2019, see https://www.japantimes.co.jp/news/2019/10/05/national/ldp-chapter-headed-tomomi-inada-got-donations-security-company-linked-former-takahama-deputy-mayor-eiji-moriyama/#.XsUenxNKjOQ, accessed 17 May 2020.

(US$2.85 million) in total to Eiji Moriyama, who was deputy mayor of Takahama town from 1977–1987. After retirement, he served in an advisory capacity and as a board member for construction and maintenance companies as well as security work in Fukui Prefecture[503]. During this time, he effectively acted as a middleman for companies in providing money and gifts to KEPCO executives. Moriyama died in March 2019. While the focus of the scandal was bribery since 2011—due to the seven-year statute of limitations on taxation—Moriyama had been deeply involved as a local fixer between KEPCO and Takahama based companies since at least 1987,[504] and it was known locally that he had played a leading role in securing construction of the first Takahama reactors during the early 1970s. The NTA investigation had been initiated in February 2018 with findings of corruption as early as June 2018, but was not disclosed at the time.[505] KEPCO senior executives were notified of the results of the investigation in September 2018, but chose not to publicly disclose it after they concluded that nothing illegal had taken place.

In September 2019, a whistleblower, reportedly inside KEPCO, released details of the investigation to the media and citizens groups in the Kansai region, as well as the KEPCO president, leaving the utility little choice. On 27 September 2019, KEPCO President Shigeki Iwane told a news conference that 20 company officials, including himself, had received a total of ¥320 million (US$3 million) worth of cash and gifts over the past seven years from "an influential man" in the local community (of Takahama) who once supported the utility's nuclear business. KEPCO officials on 27 September denied that contracts with the civil engineering company Yoshida Kaihatsu had anything to do with gifts from Moriyama to their executives.[506]

At the time, with all of KEPCO's reactors shut down since 2013 it was imperative for the company to secure restart as rapidly as possible. In this environment Moriyama's influence grew as KEPCO considered his role as deputy mayor as critical in the restart of Takahama reactors. The enormous potential for corruption as a result of the large-scale engineering retrofits and decommissioning of nuclear plants initiated in Japan following 3/11 is clear when the scale of investments made by utilities in recent years is understood. In January 2020, Kyodo news reported that the total costs for utilities for all their engineering works, including decommissioning, will reach around ¥13.46 trillion (US$123 billion) over the coming decades, with the prospects of further increases in the years ahead.[507]

Two companies for which Moriyama served as an adviser—Yoshida Kaihatsu, and a nuclear power plant maintenance company with headquarters in Hyogo Prefecture—were awarded at least ¥11.3 billion (US$104 million) in contracts between 2015–2018 for work related to KEPCO

503 - Ban Hideyuki, "Nuclear Mafia Exposed in Kansai Electric Power Co. (Kanden) Scandal ~ METI pleads ignorance of bribes and kickbacks driving the nuclear industry", Citizens Nuclear Information Center, 3 December 2019, see http://cnic.jp/english/?p=4685, accessed 17 May 2020.

504 - Eric Johnston, "A closer look at Kansai Electric and its gift-giving scandal", *Japan Times*, 29 March 2020, see https://www.japantimes.co.jp/news/2020/03/29/business/kansai-electric-gift-giving-scandal/#.XsUV5RNKjOQ, accessed 17 May 2020.

505 - Kansai Electric, "Investigation Report from Third Party Committee on the Incident of Receipt of Cash and Gifts", 14 March 2020, see https://www.kepco.co.jp/english/corporate/ir/brief/pdf/2020_mar14_2.pdf, accessed 17 May 2020.

506 - Ibidem.

507 - *Kyodo News*, "Costs for managing Japan's nuclear plants to total 13 trillion yen", 15 January 2020, see https://english.kyodonews.net/news/2020/01/8722fafaff9b-costs-for-managing-japans-nuclear-plants-to-total-13-trillion-yen.html, accessed 17 May 2020.

reactors in the prefecture.[508] Further disclosures in early October 2019 included KEPCO executives at the Ohi nuclear plant admitting that they had received gifts and money from Moriyama.[509]

In November 2019, the scandal escalated when it was disclosed by a Fukui prefectural investigation panel that 109 employees of the Fukui prefectural Government, including high-ranking officials, took cash, gift certificates, gold coins and various other gifts from Moriyama, who advised a local engineering and construction company which received contracts from KEPCO for work at the Takahama reactors.[510] The current mayor of Takahama town was also found to have accepted gifts from Moriyama,[511]—he was nevertheless re-elected for a fourth term in April 2020.[512] The investigation panel reported that it had found no particular connection between the deputy mayor and the prefectural government's safety and environment department, which oversees nuclear safety measures. As the *Asahi Shimbun* reported however, "at least one official in the scandal worked for the safety and environment department after taking Moriyama's gifts."[513]

In late November 2019, it came to light that the town of Takahama had received "donations" of least ¥4.3 billion (US$40 million) since around 1970 from KEPCO.[514] Sixty percent of the donations were given to the town just prior to the start of operations of Takahama-3 and -4 in 1984. Local municipal Governments are not legally required to report to the central Government how donations from electric power companies are used. The donations are separate from tax revenue and direct government financing to nuclear plant host communities. In 2019, Takahama town received ¥2.4 billion (US$224 million) in subsidies from the central Government.[515] However, Takahama city officials said they do not know how contributions were spent and that anonymous donors provided some of them.

Tatsuji Sugimoto, the pro-nuclear governor of Fukui Prefecture, stated at the time of the initial KEPCO disclosures in September 2019, "that the whole act is so outrageous, as it did great harm to the relationship of trust with communities hosting (nuclear plants)."[516] The general view was that approval by Sugimoto for KEPCO reactors Mihama-3, and Takahama-1 and -2, to restart as scheduled in August 2020, June 2020 and February 2021 respectively, would be further

508 - *The Asahi Shimbun*, "Official worked both sides in Kansai Electric money scandal", 2 October 2019, see http://wwaw.asahi.com/ajw/articles/AJ201910020041.html, accessed 16 May 2020.

509 - Takeshi Terada and Ikuko Ando, "KEPCO execs at Oi nuclear plant also received gifts from neighboring town official", *The Mainichi Shimbun*, 8 October 2019, see https://mainichi.jp/english/articles/20191008/p2a/00m/0na/005000c, accessed 16 May 2020.

510 - *Jiji Press*, "109 Fukui Officials Took Gifts from Key Person in Nuclear Biz Scandal", as published on *Nippon.com*, 22 November 2019, see https://www.nippon.com/en/news/yjj2019112200427/109-fukui-officials-took-gifts-from-key-person-in-nuclear-biz-scandal.html, accessed 17 May 2020.

511 - *The Mainichi Shimbun*, "Election campaign starts for Fukui town at heart of gift-giving scandal", 14 April 2020.

512 - *Kyodo News*, "Takahama mayor linked to Kepco bribery scandal re-elected", as published by *Japan Times*, 20 April 2020, see https://www.japantimes.co.jp/news/2020/04/20/national/politics-diplomacy/takahama-mayor-yutaka-nose-kepco-bribery-scandal-reelected/#.XsUNrhNKjOQ, accessed 17 May 2020.

513 - *The Asahai Shimbun*, "EDITORIAL: Scandal over Fukui official's shady gifts goes far and wide", 25 November 2019, see http://www.asahi.com/ajw/articles/AJ201911250032.html, accessed 17 May 2020.

514 - *Kyodo News*, "Kansai Electric Power Incorporated: repeatedly gave donations to nuclear plant host town", as published by *Market Screener*, 23 November 2019, see https://www.marketscreener.com/THE-KANSAI-ELECTRIC-POWER-6491273/news/Kansai-Electric-Power-Incorporated-repeatedly-gave-donations-to-nuclear-plant-host-town-29635018/, accessed 17 May 2020.

515 - Ibidem

516 - Ibidem.

delayed unless there was resignations from KEPCO management.[517] The disclosures that over 100 local officials working for Sugimoto's prefectural government were also embroiled in the scandal caused widespread condemnation across the Kansai region and wider Japan, once again reminding the public of the operations of Japan's nuclear village, seen as a major factor in the Fukushima Daiichi triple reactor meltdown. As the scandal escalated in October 2019, KEPCO Chair Makoto Yagi and four other company executives announced their resignation.[518]

The Third-Party Committee, which was established by KEPCO in October 2019, reported in March 2020 that in fact 75 KEPCO officials had received payments and gifts amounting to ¥360 million (US$3.4 million).[519] The Committee concluded that multiple causes led to the corruption, including "non transparent and incorrect "local orientedness" (that) justified problematic behaviors" and that an underlying fundamental cause was "the introverted corporate culture spreading throughout KEPCO…"[520]

Lawyers acting for NGOs and citizens across the Kansai region, Fukui Prefecture and wider Japan criticized the limited scope of the Committee report.[521] In late March 2020, the same lawyers filed an application to the Osaka District Prosecutor's Office seeking a criminal investigation into KEPCO.[522] Attempting to put the scandal behind them, on 14 March 2020, KEPCO announced that its Executive Vice President Takashi Morimoto, will replace President Shigeki Iwane as a result of the corruption scandal.[523]

The negative impact on KEPCO's operations was reflected in a downgrading of the company's credit-ratings outlook from stable to negative in late March 2020, which reflected Moody's "concerns over Kansai Electric's oversight, control and governance matters, which increases risk to the ongoing operation of its nuclear reactors".[524]

As the Citizens Nuclear Information Center (CNIC) reported, the public disclosures of the KEPCO scandal are a glimpse into the Japanese electricity utilities off-the-book funding. As detailed in the 2005-book "Tokyo Blackout" by Masataka Nakano, utilities award a contract at a price 20 percent higher than the market price, and force local businesses to funnel back the profits. The illicit funds are distributed not only to the utility but also to the Federation of

517 - WNISR2019 reported on earlier delays to restart announced by KEPCO during 2019, with expectation of further delays. See KEPCO, "About the state of implementation of safety improvement measures construction of Takahama power plant 1 and 2 and Mihama power plant 3", 4 February 2019 (in Japanese), see https://www.kepco.co.jp/corporate/pr/2019/0204_2j.html; and KEPCO, "State of Implemetation of safety improvement measures construction—Takahama Units 1 and 2, and Mihama Unit 3", 4 February 2019, see https://www.kepco.co.jp/corporate/pr/2019/pdf/0204_2j_01.pdf, both accessed 18 May 2020.

518 - *Kyodo News*, "Kansai Electric chairman resigns to take responsibility for scandal", 9 October 2019, see https://english.kyodonews.net/news/2019/10/a080f7b04b27-breaking-news-kansai-electric-endorses-chairmans-resignation-at-board-meeting.html, accessed 17 May 2020.

519 - *Kyodo News*, "Kansai Electric names new president following gift scandal", 14 March 2020, see https://english.kyodonews.net/news/2020/03/9859d9f74e2d-update1-kansai-electric-names-new-president-following-gift-scandal.html, accessed 17 May 2020.

520 - Kansai Electric, 14 March 2020, op. cit.

521 - Comity Decouncing the Fraudulent Money Transactions of the Kepco NPPs, "Statement on the final report of the third-party committee", 14 March 2020 (in Japanese), see http://kandenakan.html.xdomain.jp/seimei.pdf, accessed 21 May 2020.

522 - Various Organisation, "Offer upon receiving a report from a third-party committee", 26 March 2020 (in Japanese), Letter to KEPCO, see http://kandenakan.html.xdomain.jp/0326.html.

523 - Kansai Electric, "Personal Affairs of our Board Members", 14 March 2020, see https://www.kepco.co.jp/english/corporate/ir/brief/pdf/2020_mar14_1.pdf, accessed 17 March 2020.

524 - Moody's Investor Services, "Moody's affirms Kansai Electric's A3 ratings but changes outlook to negative", 24 March 2020, see https://www.moodys.com/research/Moodys-affirms-Kansai-Electrics-A3-ratings-but-changes-outlook-to--PR_420254, accessed 20 May 2020.

Electric Power Companies, local governments, Diet members, and many others. The author of the book dubbed this system the "Electric Power Monster System." As CNIC concluded, "The Kanden (KEPCO) scandal has unveiled a part of this monster system"[525] and that "The government should not consider this scandal as an isolated incident committed by KEPCO. Instead, it should regard this as a problem inherent to the electric power industry. The number of similar cases in which electric power companies placed construction and other orders with local dealers run by or affiliated with local influential persons is too numerous to mention."[526]

Hiroshima Lawsuit

Shikoku Electric Power Company has had a troubled start to 2020. A power outage and technical failures during nuclear fuel removal combined with a legal ruling that has forced an extended shutdown of its only remaining operational reactor, Ikata-3, located on the island of Shikoku, has contributed to further doubts over the long-term sustainability of Japanese nuclear policy. It will likely mean that Ikata-3 will remain idled for most of the remainder of 2020.

On 12 January 2020, one control rod (out of a total of 48) was accidentally lifted out of the Ikata-3 containment vessel. The reactor had been undergoing refueling and maintenance at the time, having been shut down on 26 December 2019.[527] On 25 January 2020 an "earth ground," a type of electrical fault, led to the plant depending upon an emergency generator. The plant operated on emergency power for around 30 minutes. "In my view, the control rod issue was the most risky," NRA Chairman Toyoshi Fuketa said during a news briefing on 29 January 2020, adding that "to the best of my knowledge, this was the first such event anywhere in the world."[528] A series of investigations by Shikoku Electric into both, the loss of power and control rod removal, were published between February and March 2020.[529] Ikata-3 is one of four commercial reactors in Japan that has been operating with uranium-plutonium Mixed Oxide fuel (MOX).

On 17 January 2020, the Hiroshima High Court ruled in favor of a lawsuit brought by local residents within a 50-kilometer radius of the Ikata plant. In 2018, they had filed an injunction against operation of Ikata-3 on the grounds that an active fault, the median tectonic line and Japan's longest fault system, may lie only 600 meters off the coast of the reactor site. Shikoku Electric had contested that sonic testing as had been carried out could confirm the presence of active faults in proximity to Ikata. The lawsuit argued that Shikoku Electric had underestimated the seismic threat at the plant, and that it could be two to three times more powerful than anticipated. The plaintiffs had also presented evidence of a volcanic risk to the reactor site and the court ruled that Shikoku Electric had underestimated the impact of a possible eruption of

525 - CNIC, "Nuclear Mafia Exposed in Kansai Electric Power Co. (Kanden) Scandal ~ METI pleads ignorance of bribes and kickbacks driving the nuclear industry", 3 December 2019, op. cit.

526 - CNIC, "Pre-arranged Conclusion: Kansai Electric Power Co.'s attempt to trivialize the scandal is impermissible", Citizens Nuclear Information Center, 3 October 2019, see https://cnic.jp/english/?p=4648, accessed 17 May 2020.

527 - *Kyodo/Jiji Press*, "Control rod mistakenly removed from Ikata reactor in Ehime during maintenance", as published by *The Japan Times*, 13 January 2020, see https://www.japantimes.co.jp/news/2020/01/13/national/control-rod-mistakenly-removed-reactor-ikata-nuclear-power-plant-shikoku-electric/#.XsRQ6xNKjOQ, accessed 15 May 2020.

528 - *Nucleonics Week*, "Shikoku Electric's Ikata-3 may remain offline for most of 2020", 30 January 2020.

529 - Shikoku Electric Power Company, "About continuous trouble at Ikata power station", May 2020 (in Japanese), see https://www.yonden.co.jp/publish/page_12.html, accessed 15 May 2020.

Mount Aso.[530] While the original injunction request was rejected in March 2019, the residents appealed, and on 17 January 2020 the Hiroshima High Court ordered that the reactor should not operate.[531] In addition to accepting the plaintiffs case on the possibility of an active fault, the court also concluded that Shikoku Electric's assessment on active faults was insufficient and that the NRA either was in error or had failed to sufficiently evaluate risks, when it concluded that there was no problem with Shikoku Electric's research.[532] The court ruling requires the NRA to also conduct more robust inspections at Ikata. The company's share value dropped by 6-percent in the following 24 hours.

It was the second time the court had ruled against operation of Ikata-3 (see WNISR2018), the first had been subsequently overturned on appeal. In the first case, the reactor was offline for most of 2018 until October when it was restarted. The reactor had operated for 14 months until December 2019, when it was shut down for maintenance and refueling. It was due to restart operation on 27 April 2020, prior to the Hiroshima High Court ruling. Satoru Katsuno, Chair of the Federation of Electric Power Companies (FEPC) stated that "(The ruling) is very regrettable. With few energy resources in Japan, nuclear energy has a major role to play in providing a stable supply of electricity and as a way to deal with global warming. Making every effort to meet new safety standards, we will also do our utmost to improve explanations to those living in host municipalities and general society".[533]

Shikoku Electric on 19 February 2020 filed an appeal with the Hiroshima High Court seeking a reversal of the decision,[534] with the expectation that a judgement will be issued during the last quarter of the year.

Multiple Reactor Shutdowns

The first forced shutdowns as a result of NRA emergency security regulations began in spring 2020. Utilities in Japan were required to construct and install new emergency control-rooms, standby power-supplies and reactor coolant-pumps, to enable cooling procedures via remote control. The emergency off-site control rooms were to serve as back-up facilities to be used in the event of a terrorist attack and to prevent fuel melt. The facilities and equipment were required to be in place no later than five years after each reactor received regulatory restart approval. Described as a near total shutdown of Japan's reactor fleet, the NRA decision contributed to a 19-percent plunge of the three utilities' share value as of April 2019.[535] All

530 - *The Mainichi Shimbun*, "Editorial: Court order to halt Ehime nuclear reactor serves as safety inspection warning", 18 January 2020, see https://mainichi.jp/english/articles/20200118/p2a/00m/0na/006000c, accessed 15 May 2020.

531 - *The Asahi Shimbun*, "Residents win appeal to halt Ikata reactor over safety fears", 17 January 2020, see http://www.asahi.com/ajw/articles/AJ202001170057.html; and Shikoku Electric Power Company, "Decision on temporary suspension of operation of No. 3 operation of Ikata Power Station in Hiroshima High Court appeal", 17 January 2020 (in Japanese), see https://www.yonden.co.jp/press/2019/__icsFiles/afieldfile/2020/01/17/pr006_1.pdf; both accessed 15 May 2020.

532 - *The Mainichi Shimbun*, "Editorial: Court order to halt Ehime nuclear reactor serves as safety inspection warning", 18 January 2020, op. cit.

533 - *The Asahi Shimbun*, "Residents win appeal to halt Ikata reactor over safety fears", 17 January 2020, see http://www.asahi.com/ajw/articles/AJ202001170057.html, accessed 27 August 2020.

534 - *Platts Nuclear News Flashes*, "Shikoku Electric appeals ruling keeping Ikata-3 offline", 19 February 2020.

535 - Robin Harding, "Japan's nuclear reactors face new near-total shutdown", *Financial Times*, 25 April 2019, see https://www.ft.com/content/1b2c395e-6724-11e9-9adc-98bf1d35a056, accessed 29 April 2019.

utilities have reported that they are behind schedule in the construction of their "contingency" facilities.[536]

Kyushu Electric Power Company missed its deadline for its two reactors at Sendai. It was required to finish installing counter-terrorism facilities at the Sendai-1 and -2 reactors by 17 March and 21 May 2020, respectively.[537] As a result, **Sendai-1** has been shut down since 16 March 2020[538] and is scheduled for restart on 26 December 2020. While **Sendai-2** was shut down on 20 May 2020 after only operating for four months following its maintenance and inspection outage completed in January.[539] It is scheduled for restart on 26 January 2021.

KEPCO's **Takahama-3**, originally due to restart following maintenance and inspection sometime between April and May 2020, has not been restarted as of 1 July 2020.[540] During its outage, damage to the steam-generator tube support-plate was identified.[541] It was scheduled to be shut down from 2 August to 22 December 2020 for completion of emergency upgrades. **Takahama-4** was shut down in September 2019 for maintenance and refueling and was restarted on 26 February 2020.[542] It is scheduled to be shut down from 7 October to 10 February 2021. The shutdown of the Takahama reactors due to emergency measures provision is expected to cost Kansai Electric ¥33.7 billion (US$309 million).[543]

Shikoku Electric's Ikata-3 reactor was due to be shut down in March 2020 as a result of the NRA emergency measures. However, the reactor has not restarted after completing maintenance due to the Hiroshima District Court ruling (see section on the Hiroshima Lawsuit).

Reactor Closures

No additional reactors were formally declared for decommissioning in the year to 1 July 2020. 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 14.7 percent of Japan's operating nuclear capacity as of March 2011.[544] Together with the ten Fukushima units, the total rises to 21 reactors and 15.2 GW

536 - *The Yomiuri Shimbun*, "NRA, power utilities should promote in-depth dialogue for nuclear safety", *The Japan News*, 8 May 2019, see http://the-japan-news.com/news/article/0005725420.

537 - *Argus Media*, "Japan's Kyushu to shut Sendai reactor for eight months", 18 May 2020, see https://www.argusmedia.com/en/news/2106140-japans-kyushu-to-shut-sendai-reactor-for-eight-months, accessed 18 May 2020.

538 - *Kyodo News*, "Kyushu Electric halts Sendai reactor due to delay in terrorism measures", as published by *The Japan Times*, 16 March 2020, see https://www.japantimes.co.jp/news/2020/03/16/national/kyushu-electric-halts-sendai-reactor/#.XsWCiRNKjOQ, accessed 18 May 2020.

539 - Argus Media, "Japan's Kyushu to shut Sendai reactor for eight months", 18 May 2020, op. cit.

540 - KEPCO, "Operation results of nuclear power plants (FY2019)", 3 April 2020, see https://www.kepco.co.jp/corporate/pr/2020/0403_1j.html, accessed 18 May 2020.

541 - KEPCO, "Regarding the periodic inspection status of Takahama Power Station Unit 3 (Continued report on the status of inspection regarding damage to steam generator heat transfer tubes)", 17 April 2020, see https://www.kepco.co.jp/corporate/pr/2020/0417_2j.html; and KEPCO, "Periodic inspection status of Takahama Power Station Unit 3 (damage to steam generator heat transfer tubes)", 18 February 2020, see https://www.kepco.co.jp/corporate/pr/2020/0218_2j.html; both accessed 18 May 2020.

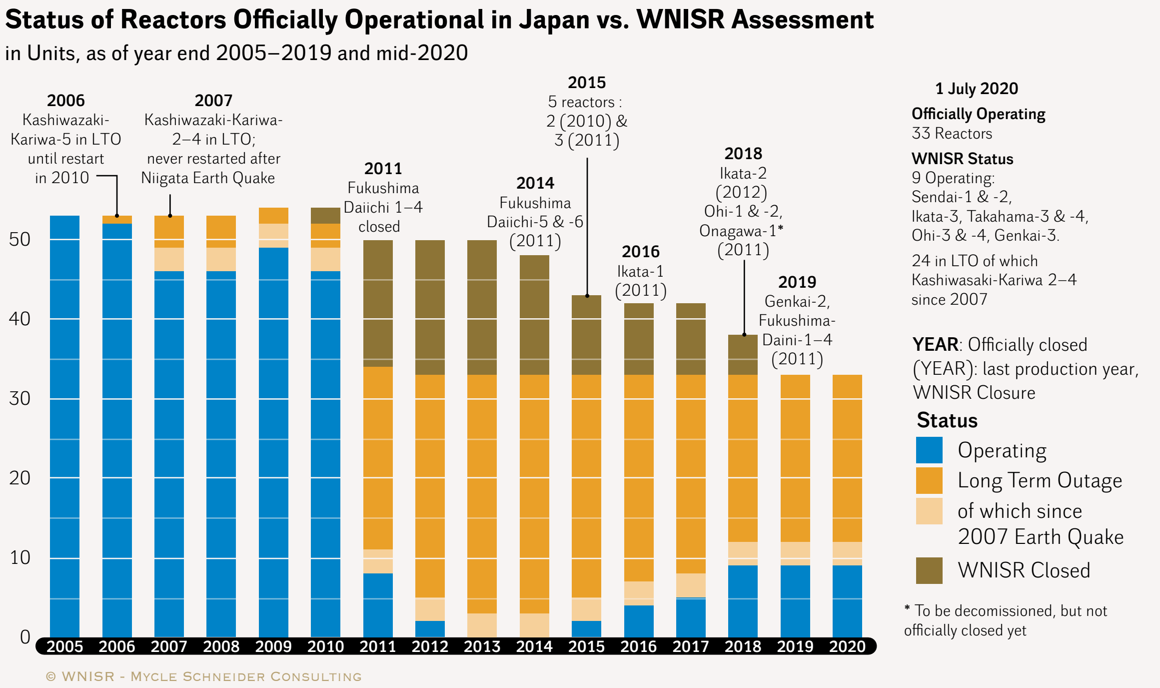
542 - KEPCO, "(Notice) Resumption of full-scale operation of Unit 4 of Takahama Power Station", 26 February 2020 (in Japanese), see https://www.kepco.co.jp/corporate/pr/2020/0226_3j.html, accessed 18 May 2020.

543 - *NEI Magazine*, "Japanese reactor restarts delayed for safety upgrades", 31 January 2020, see https://www.neimagazine.com/news/newsjapanese-reactor-restarts-delayed-for-safety-upgrades-7748324, accessed 18 May 2020.

544 - 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.

or just under 35 percent of nuclear capacity prior to 3/11 that has now been permanently removed from operations (see Figure 39 and Table 7).

Figure 39 · Status of the Japanese Reactor Fleet



Sources: Various, Compiled by WNISR, 2020

TEPCO's nuclear plant at Kashiwazaki Kariwa in Niigata Prefecture saw progress of sorts during the past year towards possible decommissioning of one or more of the seven reactors at the site. On 26 August 2019, at a meeting between Masahiro Sakurai, the mayor of Kashiwazaki City and TEPCO's President Tomoaki Kobayakawa, it was announced that the company would consider plans to decommission one or more reactors at the site within five years of restart of Units 6 and 7.[545] (See The Case of TEPCO's Kashiwazaki Kariwa).

The Japanese nuclear fleet's mean age now stands at 29.4 years, with 13 units over 31 years (see Figure 40).

545 - *The Asahi Shimbun*, "EDITORIAL: Put state in charge of TEPCO's plan for reactor restarts", 10 September 2019, see http://www.asahi.com/ajw/articles/AJ201909100038.html, accessed 20 May 2020.

Table 7 · Official Reactor Closures Post-3/11 in Japan (as of 1 July 2020)

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, 2020

Notes

BWR: Boiling Water Reactor; PWR: Pressurized Water Reactor; FBR: Fast Breeder Reactor; LTS: Long-Term Shutdown.

TEPCO: Tokyo Electric Power Company; KEPCO: Kansai Electric Power Company; JAEA: Japan Atomic Energy Agency; JAPC: Japan Atomic Energy Agency.

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.

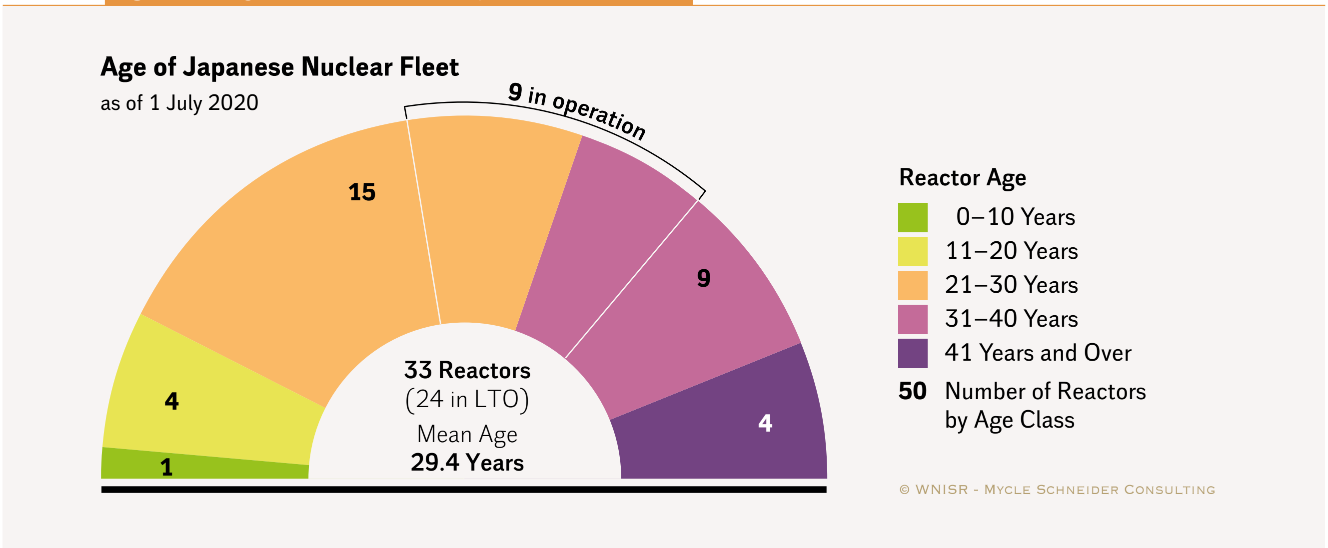
d – *WNN*, "Shikoku decides to retire Ikata 2", *World Nuclear News*, 27 April 2018, see http://www.world-nuclear-news.org/C-Shikoku-decides-to-retire-Ikata-2-2703184.html, accessed 22 July 2018.

e – *The Mainichi*, "Japan decides to scrap trouble-plagued Monju prototype reactor", 21 December 2016, see http://mainichi.jp/english/articles/20161221/p2g/00m/0dm/050000c, accessed 21 December 2016.

f – The Monju reactor was officially in Long-Term Shutdown or LTS (IAEA-Category Long Term Shutdown) since December 1995.

g – The decision to close the reactor was announced in October 2018.

Figure 40 · Age Distribution of the Japanese Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2020

Restart Prospects

The Mainichi Shimbun reported in November 2019 that safety retrofit costs at nuclear power plant were estimated by Japanese utilities to have increased fivefold since 2013 to ¥5.38 trillion (US$50 billion.[546] In 2013, and before the newly created Nuclear Regulatory Authority (NRA) applied revised regulatory conditions, the nine utilities with reactors had allocated together just under ¥1 trillion (US$9.3 billion) for safety measures. The current cost estimate for Japanese reactors is higher than the total expenditure for post-Fukushima measures carried out in 2016 for all the reactors in the world, according to a report by *Platts Electric Power*.[547]

The costs to TEPCO of safety upgrades at the seven-reactor Kashiwazaki Kariwa site in Niigata were ¥1.17 trillion (US$10.9 billion), the highest for any utility. All of those the reactors remain in LTO, with a possible restart of **Kashiwasaki-6 and -7** from 2021—but only if local approval is secured. TEPCO had estimated in 2013 that costs would be ¥70 billion (US$653 million). For a number of utilities, the final cost of anti-terrorism upgrades had yet to be calculated, according to *Mainichi*. Clearly costs are continuing to rise; *Nikkei* for example had reported in July 2019 that utilities were estimating costs at ¥4.8 trillion (US$44.2 billion).[548]

All currently operating reactors in Japan are Pressurized Water Reactors (PWRs)—the destroyed Fukushima Daiichi units were Boiling Water Reactors (BWRs). As of 1 July 2020, 16 reactors remain under NRA safety review (out of a total of 25 that have applied since July 2013 of which nine were restarted); 24 reactors remain in LTO. Not all of these will restart, with many questions and disagreements over seismic issues, and many plants far back in the review

546 - *The Mainichi Shimbun*, "Japan nuclear plant safety costs increase 5-fold over 6 years to 5.4 trillion yen", 16 November 2019, see https://mainichi.jp/english/articles/20191116/p2a/00m/0na/004000c.

547 - *S&P Global Insight*, "Nuclear safety upgrades post-Fukushima cost $47 billion", Platts Electric Power, 28 March 2016, see https://blogs.platts.com/2016/03/29/nuclear-safety-upgrades-post-fukushima/, accessed 20 May 2020.

548 - *Nikkei Review*, "Nuclear safety costs in Japan surge to staggering heights", 9 July 2019, see https://asia.nikkei.com/Business/Energy/Nuclear-safety-costs-in-Japan-surge-to-staggering-heights, accessed 20 May 2020.

and screening queue. There are officially two reactors under construction (Shimane-3 and Ohma). WNISR has pulled Ohma off the list, as no active construction could be substantiated.

Restarts for Kansai Electric Power Company's (KEPCO) Pressurized Water Reactors (PWRs) **Takahama-1 and -2**, and **Mihama-3**, which passed NRA review for respective upgrading plans in 2016, have been further delayed. In March 2020, KEPCO announced that completion of safety retrofits would take four months longer than planned.[549] These three reactors, which are 46, 45 and 44 years old respectively, were granted lifetime operation approval to 60 years by the NRA in 2016.[550] Respective restart schedules have all been revised several times over recent years. The latest delays would mean restart of Takahama-1 no earlier than September 2020, with Takahama-2 in May 2021, and Mihama-3 no earlier than October 2020. All of these restart dates look unlikely to be achieved. The impact of the NRA ruling requiring secondary emergency control centers at nuclear reactors may impact the restart of the Mihama-3 reactor. In June 2020, a Kansai Electric spokesperson stated that the company "has yet to form a new policy," regarding the Mihama-3 restart.[551] The NRA requires that the emergency safety center at Mihama-3 be completed by 25 October 2021, and one option being considered is that the reactor remains in LTO until then or later. However, assuming that all three reactors will be operating by the end of 2021, and other engineering work is completed at Takahama-3 and -4, seven of the twelve reactors operating in Japan will be owned by KEPCO, with an installed capacity of 6.25 GW. As reported, KEPCO has been at the center of a bribery and corruption scandal during the last year, including specifically at engineering work conducted at the Takahama reactor site. However, unless there are further revelations, it is unlikely that this scandal will significantly affect restart of the Takahama and Mihama reactors.

On 26 February 2020, the NRA commissioners granted permission to Tohoku Electric Power Company to make changes to the **Onagawa-2** reactor (i.e. basic design approval).[552] The reactor, situated on the Ishinomaki peninsula on the Pacific coast of Miyagi Prefecture, was the 16th in Japan and the fourth BWR to win approval under the NRA's new safety standards. This major step in the approval of the safety of the reactor was reported as meaning that Onagawa-2 will be the first BWR to restart operations under the new guidelines, with completion of works planned by the owner scheduled for 2021. However, two months after securing NRA regulatory approval for its Onagawa-2 BWR, the President of Tohoku Electric Power Company announced on 30 April 2020 a two-year delay in completion of construction work at the reactor site.[553] Work is now planned to be finished by March 2023.[554] Construction work at the reactor,

549 - *Jiji Press*, "Kansai Electric Puts Off Restart of N-Reactors in Fukui Pref." 31 March 2020, see https://www.nippon.com/en/news/yjj2020033100928/kansai-electric-puts-off-restart-of-n-reactors-in-fukui-pref.html, accessed 20 May 2020.

550 - Noriyuki Ishii, "NRA Approves Extensions of Operating Periods to 60 Years for Takahama-1 and -2, the First for Aging Reactors", JAIF, 22 June 2016, see https://www.jaif.or.jp/en/nra-approves-extensions-of-operating-periods-to-60-years-for-takahama-1-and-2-the-first-for-aging-reactors/; and Noriyuki Ishii, "NRA Approves Extension of Operating Lifetime for Mihama-3 through 2036", JAIF, 17 November 2019, see https://www.jaif.or.jp/en/nra-approves-extension-of-operating-lifetime-for-mihama-3-through-2036/; both accessed 26 April 2020.

551 - *Platts Nuclear News Flashes*, "NRA approves Kansai Electric's Mihama-3 backup safety facility plans", 3 June 2020.

552 - JAIF, "NRA Approves Changes to Reactor Installation for Onagawa-2 under New Regulatory Standards", 27 February 2020, see https://www.jaif.or.jp/en/nra-approves-changes-to-reactor-installation-for-onagawa-2-under-new-regulatory-standards/, accessed 21 May 2020.

553 - Tohoku Electric, "Overview of April Presidential Press Conference", 30 April 2020, see https://www.tohoku-epco.co.jp/news/press/1214692_2560.html, accessed 20 May 2020.

554 - JAIF, "NRA Approves Changes to Reactor Installation for Onagawa-2 under New Regulatory Standards", 27 February 2020, see https://www.jaif.or.jp/en/nra-approves-changes-to-reactor-installation-for-onagawa-2-under-new-regulatory-standards/, accessed 20 May 2020.

including a 29-meter extended seawall and additional seismic retrofit measures, according to Tohoku Electric in February 2020, had been scheduled to be completed before March 2021, to be then followed by pre-operational inspections by the NRA and restart, expected to be towards the end of 2021. With NRA approval it was reported in February 2020 that Onagawa-2 would the first BWR to resume operations in Japan.[555] As of November 2019, Tohoku Electric had committed ¥340 billion (about US$3.1 billion) in safety retrofits at the site.[556]

Doubts persist over the actual condition of the Onagawa reactors, including unit 2. The Onagawa site is the closest nuclear plant to the epicenter of the 3/11 earthquake. Unit 2 was subcritical in startup mode on 3/11, while Units 1 and 3 were in full operation. In January 2017, the utility disclosed to the NRA that the reactor building had sustained 1,130 cracks in the walls and "lost an estimated 70 percent of structural rigidity" in the 3/11 earthquake.[557] The disclosures led Tohoku to push back restart schedule from 2018 to 2019 and then beyond 2020. The disclosures to the NRA followed an architectural investigation which identified that structural rigidity, the ability to withstand earthquakes and other stresses from outside without being distorted, was concentrated in the upper third of the reactor building with the third floor only retaining 30 percent of its integrity compared with July 1995 when the reactor began operation. It also confirmed a 25 percent loss of structural integrity in the two above-ground floors and three basement levels.

Significantly, the disclosure contrasts starkly with the assessment and conclusions of a high-profile IAEA mission to the plant in 2012.[558] The IAEA mission included a "structures team" assigned to observe and collect information on the performance of the structural elements of buildings. They reported that, as far as cracks in Unit 2 are concerned, they were "less than 0.3 mm, although at some locations there were cracks of approximately 0.8 mm. These minor cracks do not affect the overall integrity of the structure." The IAEA concluded: "The lack of any serious damage to all classes of seismically designed facilities attests to the robustness of these facilities under severe seismic ground shaking", and that, "the structural elements of the NPS [Nuclear Power Station] were remarkably undamaged given the magnitude and duration of ground motion experienced during this great earthquake."[559]

The NRA draft assessment of Onagawa-2 in November 2019, garnered 979 public submissions where, "many local citizens expressed concerns over the threat posed to the plant by earthquakes and tsunami but the NRA dismissed their comments."[560] In November 2019, a group of Ishinomaki citizens filed a request with the Sendai District Court for an injunction

555 - Shota Ushio and Yuzo Yamaguchi, "Onagawa-2 to likely be first BWR to restart since Fukushima I accident", *S&P Global Platts*, 26 February 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/022620-onagawa-2-to-likely-be-first-bwr-to-restart-since-fukushima-i-accident, accessed 20 May 2020.

556 - *Kahoku Shimpo*, "Onagawa Nuclear Power Plant No. 2—Safety Measures ¥ 340 Billion", 29 March 2019 (in Japanese), see https://www.kahoku.co.jp/tohokunews/201903/20190329_11016.html, accessed 26 April 2019; and *The Mainichi Shimbun*, "Editorial: Reactor restart OK a reminder Japan must abandon nuclear power", 28 November 2019, see https://mainichi.jp/english/articles/20191128/p2a/00m/0na/007000c, accessed 20 May 2020.

557 - *The Asahi Shimbun*, "1,130 cracks, 70% rigidity lost at Onagawa reactor building", 18 January 2017.

558 - IAEA, "Mission To Onagawa Nuclear Power Station To Examine The Performance Of Systems, Structures And Components Following The Great East Japanese Earthquake And Tsunami", Mission Report to the Government of Japan, 30 July–11 August 2012, Onagawa and Tokyo (Japan), IAEA Department Of Nuclear Safety And Security, Department Of Nuclear Energy, see https://www.iaea.org/sites/default/files/iaeamissiononagawa.pdf, accessed 26 April 2019.

559 - Ibidem.

560 - *The Asahi Shimbun*, "Onagawa reactor passes screening under new NRA safety standards", 26 February 2020, see http://www.asahi.com/ajw/articles/13166013, accessed 21 May 2020.

that, if granted, would prohibit the Miyagi Prefecture governor and the Ishinomaki mayor from approving restart to the reactor.[561]

As of 1 July 2020, the utility had not applied for NRA review of **Onagawa-3** which began operation in May 2001. Tokoku Electric's President stated in November 2018 that they were in preparation for submitting a safety review application to the NRA for the reactor, without specifying a date.[562] There are suspicions that damage sustained at Unit 3 is more significant than reported.

Other reactor operators remain in ongoing dialogue with the NRA over multiple issues at their respective reactor sites. Hokkaido Electric Power Company, for example, continues to present evidence to the regulator claiming that the seismic risk to the **Tomari** site, which hosts three PWRs, would be limited so that the reactors could safely operate. Further field investigations into the geological structures around the site are ongoing as of April 2020.[563] The utility is struggling with a lower customer base, and continues like other Japanese utilities to rely on debt financing to cover the costs of reactor retrofits.[564] There are no near-term prospects for restart of the Tomari reactors.

During 2019, the future prospects for the planned TEPCO twin Advanced Boiling Water Reactors (ABWR) at Higashidori surfaced with reports of possible partnership with other Japanese utilities. The TEPCO Higashidori-1 power plant in Aomori prefecture, referred to as Higashi Dori-1 (TEPCO) in IAEA-PRIS, not to be confused with the Higashidori-1 reactor owned by Tohoku Electric (referred to as Higashi Dori (Tohoku) in IAEA-PRIS) and also located at the adjacent site in Aomori, was due to be constructed from 2011. The initial project was for two 1385 MW ABWRs. Granted a construction permit in December 2010, TEPCO began site preparation in January 2011,[565] but plans for formal construction to begin in April 2011 was suspended following the 3/11 events. Commercial operation of unit 1 was originally scheduled for March 2017.[566] A seismic assessment was initiated in 2018 by TEPCO, specifically looking at the possibility of an active fault line under the power plant site and which was due to be completed in FY 2020.[567] TEPCO has been seeking partners for covering the cost of construction without success since 2018, with Tomoaki Kobayakawa, the then company President stating that, "It's necessary to form a consortium for building a nuclear plant that is excellent in safety, technology and economy".[568] At that time, other utilities listed as possible partners were Tohoku Electric, Chubu Electric Power Co., and JAPCo, as well as Kansai Electric

561 - *The Asahi Shimbun*, "EDITORIAL: Safety concerns linger although Onagawa reactor cleared to restart", 28 November 2019, see http://www.asahi.com/ajw/articles/AJ201911290036.html, accessed 20 May 2020.

562 - *NW*, "Tohoku Electric preparing to apply to NRA for Onagawa-3 safety review", 1 November 2018.

563 - Hokkaido Electric Power Company, "Documents to be submitted to the review meeting regarding compliance with new regulatory standards for nuclear power plants", 856th Nuclear Power Plant New Regulatory Standards Compliance Meeting, held April 16, 2020)", see http://www.hepco.co.jp/energy/atomic/info/document.html#MEETING_856, accessed 21 May 2020.

564 - Moody's, "Rating Action: Moody's affirms Hokkaido Electric's P-2 rating", 13 March 2020.

565 - TEPCO, "Higashidori Nuclear Power Station—Construction Plan Overview", Undated, see https://www.tepco.co.jp/en/hd/ourbusiness/nuclear/higashi-dori/index-e.html, accessed 21 July 2020.

566 - *NucNet*, "Construction Of Higashidori-1 (Tepco) Begins", 1 February 2011, see https://www.nucnet.org/news/construction-of-higashidori-1-tepco-begins, accessed 21 July 2020.

567 - *Jiji Press*, "Tepco to check for faults under site of new atomic plant eyed in Aomori", as published in *The Japan Times*, 30 June 2018, see https://www.japantimes.co.jp/news/2018/06/30/national/tepco-start-geological-survey-higashidori-nuclear-plant-aomori/, accessed 21 July 2020.

568 - Ibidem.

Power. As the holder of the majority of TEPCO's voting rights, the Japanese Government was reported to be supportive of such a consortium. TEPCO claimed that it would reach agreement with partners by FY 2020.[569] Given the financial status of JAPCo, there are no prospects of it contributing financing.

On 28 August 2019, TEPCO, Chubu Electric Power and two nuclear reactor vendors, Hitachi and Toshiba signed an agreement to discuss potential collaboration for "BWR [Boiling Water Reactor] business".[570] Though the agreement does not specifically name the construction of the Higashidori plant, TEPCO officials had explained the agreement in that context. In September 2019, Satoshi Katsuno, Chubu Electric's president, stated that the agreement leaves open the possibility of joint work on the Higashidori-1 project. Undoubtedly, the agreement reflects the interests of those in the Ministry of Economy, Trade and Industry (METI) determined to maintain nuclear power in Japan but conscious that the present structure is not sustainable given the state of the industry with limited domestic reactor operations and the extremely limited prospects for securing overseas contracts. A former METI official told *Nucleonics Week* in September 2019 that, "it would be natural" for TEPCO, which is controlled by the state, and Chubu Electric "to move to consolidate their nuclear operations."[571]

Chubu Electric has yet to have any of its existing reactors at Hamaoka approved for operation by the NRA, as well as facing opposition to restart from the prefectural Government. METI's leverage of Chubu to join the Higashidori project is considerable, with one analyst stating that it and may even mean that in addition to the Higashidori plant, the Hamaoka reactors may be operated by the four parties.[572]

However, in December 2019 Toshiba indicated that it is uninterested in joint operation of the Higashidori plant, "Our stakeholders won't accept it," said Midori Hara, a Toshiba spokeswoman.[573] One issue cited was Toshiba's concern that Japan's nuclear liability law maintains nuclear plant operators' unlimited liability for compensation for accidents: "Unless the law is revised, we will remain reluctant to join the Higashidori project," said Hara.[574] On 13 December 2019, TEPCO president Tomoaki Kobayakawa stated: "We're in talks with the partners...But they may have different interests in this," he added, noting that the Higashidori project could not be pursued without the partnerships.[575]

The Case of TEPCO's Kashiwazaki Kariwa

Prospects for the restart of TEPCO's Advanced Boiling Water Reactors (ABWRs) Kashiwazaki Kariwa-6 and -7 in Niigata Prefecture have taken a step forward in the past year. In November 2019, the mayor of Kashiwazaki city, one of the two host communities that must give

569 - *Kyodo News*, "Tepco and other utilities eye joint nuclear plant project in Aomori Prefecture", 16 March 2018, see https://www.japantimes.co.jp/news/2018/03/16/business/corporate-business/tepco-utilities-eye-joint-nuclear-plant-project-aomori-prefecture/, accessed 21 July 2020.

570 - Toshiba, "Basic Agreement to Discuss Potential Collaboration for Nuclear Energy Business (Boiling Water Reactors)", 28 August 2019, see https://www.toshiba.co.jp/about/press/2019_08/pr2803.htm, accessed 21 July 2020.

571 - *NW*, "Japan's Chubu may join TEPCO in Higashidori-1 project: analysts", 19 September 2019.

572 - Ibidem.

573 - *NW*, "TEPCO sees differing interests among potential partners in higashidori-1 project" 19 December 2019.

574 - Ibidem.

575 - Ibidem.

their consent before restart, accepted TEPCO's overall plan for considering decommissioning one or more reactors at the site. This was a condition imposed on TEPCO by the mayor in 2017 requiring a commitment to reduce the number of operating reactors at the site in exchange for approval by the mayor for restart of Units 6 and 7. Both reactors have been shut down since March 2012 and August 2011 respectively. While TEPCO is aiming for a restart in March 2021, significant obstacles and uncertainties remain.

When TEPCO submitted its first post-3/11 business plan to the Japanese Government in 2012, it predicted that restart of reactors at Kashiwazaki Kariwa would begin in FY2013. This was never credible. On 27 December 2017, the NRA approved the initial safety assessment of Units 6 and 7,[576] the first BWRs to reach this stage of NRA's review process.[577] On 13 December 2018, TEPCO submitted to the NRA a schedule for completion of its engineering work program on Unit 7, by which it aims to complete safety retrofits by December 2020.[578] In its third Special Business Plan in May 2017, it projected income from the reactors with three potential restart dates of 2019, 2020 and 2021.[579] WNISR2019 concluded that the earliest the reactors could restart would be 2021, but only if TEPCO were to overcome significant obstacles. As of 1 July 2020, there are diminishing prospects for TEPCO succeeding in restarting the reactors, as now planned, in March 2021.[580]

The Kashiwazaki Kariwa site has a history of major seismic activity, with repeated underestimates and non-disclosures of the seismic risks by TEPCO and resultant coverups. At the time of the licensing of the Units 6 and 7 in 1991, TEPCO presented evidence to the regulator that the nearby fault lines were not active. This was then proven to be incorrect, with TEPCO's own data showing that they were aware of active faults as early as 1980. None of this was made public until after the 2007 Niigata Chuetsu-oki quake.[581]

There are multiple seismic fault lines in the area of the Kashiwazaki Kariwa site, including through the site.[582] There are large-scale submarine active faults offshore with four main ones, three of which run along either edge of the Sado Basin, a depression between Sado Island and mainland Kashiwazaki.[583] Seismologists have long warned about the threat from major earthquakes leading to a severe nuclear accident at Kashiwazaki Kariwa.[584] Independent

576 - TEPCO, "Receipt of Approval of Revision for Reactor Installation Permit for Kashiwazaki-Kariwa NPS Units 6/7 to comply with the New Regulatory Regulations", Press Release, 27 December 2017.

577 - Justin McCurry, "Fears of another Fukushima as Tepco plans to restart world's biggest nuclear plant", *The Guardian*, 28 December 2017, see https://www.theguardian.com/world/2017/dec/28/fears-of-another-fukushima-as-tepco-plans-to-restart-worlds-biggest-nuclear-plant, accessed 16 August 2020.

578 - Platts, "Tepco to finish engineering work program at Kashiwazaki-Kariwa in 2020", *Nuclear News Flashes*, 14 December 2018.

579 - TEPCO, "Outline of the 'Revised Comprehensive Special Business Plan (The Third Plan)'", 18 May 2017, see https://www.tepco.co.jp/en/press/corp-com/release/2017/1437151_10469.html, accessed 16 August 2020.

580 - TEPCO, "FY2017 Financial Results (April 1, 2017 – March 31, 2018) Tokyo Electric Power Company Holdings, Inc.", 26 April 2018, see http://www.tepco.co.jp/en/corpinfo/ir/tool/presen/pdf/180426_1-e.pdf.

581 - Katsuhiko Ishibashi and Mitsuhisa Watanabe, "We demand that the Kashiwazaki-Kariwa Nuclear Power Plant be closed", CNIC, March-April 2008, see http://www.cnic.jp/english/newsletter/pdffiles/nit123.pdf, accessed 27 April 2019.

582 - Kashiwazaki Kariwa Nuclear Power Fault Study Group, "Kashiwazaki Kariwa Nuclear Power Station site and its surroundings—Request for a rigorous scientific review on stratigraphy of Middle and Upper Pleistocene", 22 May 2017 (in Japanese), see http://masatate.blog.fc2.com/blog-entry-55.html, accessed 27 April 2019.

583 - CNIC, "We demand that the Kashiwazaki-Kariwa Nuclear Power Plant be closed", Group of Concerned Scientists and Engineers Calling for the Closure of the Kashiwazaki-Kariwa Nuclear Power Plant, 2008, see http://cnic.jp/english/?p=1200#intro, accessed 20 May 2020.

584 - Ishibashi Katsuhiko, "Why Worry? Japan's Nuclear Plants at Grave Risk From Quake Damage", *The Asia-Pacific Journal*, 1 August 2007, Vol. 5, Issue 8, see http://apjjf.org/-Ishibashi-Katsuhiko/2495/article.html, accessed 27 April 2019.

seismologists and citizens' groups continue to oppose restart of the reactors, including based on evidence that TEPCO has relied on flawed seismic assessments;[585] meanwhile, legal challenges seeking permanent closure are ongoing.

The Niigata governor election of 10 June 2018 led to the appointment of Liberal Democratic Party (LDP)-backed candidate Hideyo Hanazumi.[586] This did not automatically mean any early restart for the Kashiwazaki Kariwa reactors. The elected governor, conscious that 65 percent of the Niigata population remains opposed to restart of any reactors at the plant, stated at the time that "as long as the people of Niigata remain unconvinced, (the reactors) won't be restarted."[587]

Niigata has a long history of opposition to the nuclear power plant, but this was exacerbated when in September 2002, following disclosures from a General Electric whistleblower, TEPCO was forced to admit that the organization had deliberately falsified data for inclusion in regulatory safety inspection reports of their reactors, a consequence of "systematic and inappropriate management of nuclear power inspections and repair work [over] a long time".[588] As a consequence, at the time, all 17 TEPCO reactors—the seven at Kashiwazaki Kariwa and the ten at Fukushima—were shut down for extended periods, and TEPCO's chairman, president, and executive vice-president all resigned. The major seismic risks at the plant were exposed by the 2007 Niigata Chuetsu-oki earthquake, which once again led to the extended shutdown of all Kashiwazaki Kariwa reactors, while Units 2, 3 and 4 have not operated since then. It is quite remarkable that official data like the IAEA-PRIS database continue to list these reactors as "in operation" although they have not provided a single kilowatt-hour in the past 13 years.

In February 2019, the NRA announced it was investigating TEPCO for ongoing safety violations, at Kashiwazaki Kariwa, as well as at Fukushima.[589]

In the aftermath of the 2002 falsification disclosures, the then governor of Niigata established a Technical Committee of 15 experts to review nuclear safety in the prefecture. This committee is currently still reviewing the Fukushima Daiichi accidents, including causes as well as ongoing assessments of the safety of the Kashiwazaki Kariwa plant. This includes meetings with NRA, where the regulator has been regularly challenged on its safety approval of the reactors.[590] A second committee, established in August 2017 by then Governor Ryuichi Yoneyama, is reviewing the health impacts of the Fukushima Daiichi accident and a third committee, also established under Yoneyama, is reviewing emergency planning in Niigata in the event of a

585 - Niigata Nippo, "At Kashiwazaki Nuclear Power Station, 'Incomplete fault investigation' residents group proposed to TEPCO", 26 January 2019 (in Japanese), see https://www.niigata-nippo.co.jp/news/national/20190126447009.html; and Tateishi Masaaki, "Kashiwazaki-Kariwa nuclear power plant, doubt on TEPCO interpretation of the Terao fault outcrop", 30 January 2019 (in Japanese), see http://masatate.blog.fc2.com/blog-entry-64.html, both accessed 27 April 2019.

586 - *The Asahi Shimbun*, "LDP-backed candidate wins governor's race in Niigata", 11 June 2019, see http://www.asahi.com/ajw/articles/AJ201806110049.html, accessed 27 April 2019.

587 - Eric Johnston, "If Niigata gubernatorial race was a litmus test, Abe and Nikai passed", *The Japan Times*, 11 June 2018, see https://www.japantimes.co.jp/news/2018/06/11/national/politics-diplomacy/niigata-gubernatorial-race-litmus-test-abe-nikai-passed/#.WzDaTxIzbOQ, accessed 27 April 2019.

588 - TEPCO, "Report on the Investigation into Inspection and Maintenance Problems at TEPCO's Nuclear Power Plants, pointed out by GE", Press Release, 17 September 2002, see http://www.tepco.co.jp/en/press/corp-com/release/02091701-e.html, accessed 27 April 2019.

589 - Yusuke Ogawa, "TEPCO sat by idly on reports of fires, glitches at nuclear plants", *The Asahi Shimbun*, 14 February 2019, see http://www.asahi.com/ajw/articles/AJ201902140054.html, accessed 27 April 2019.

590 - Tadao Yabe, "Preventing the Restart of Kashiwazaki-Kariwa Nuclear Power Station is Possible!", Local Coalition Opposed to the Kashiwazaki-Kariwa Nuclear Power Station, CNIC, 2 August 2018, see http://www.cnic.jp/english/?p=4165, accessed 27 April 2019.

severe accident at the Kashiwazaki Kariwa plant.[591] The work of the Committees was linked to the then Governor's decision on the restart of Units 6 and 7, and the committees are expected to conclude their investigations in mid-2020. The incoming Governor has affirmed since his election that he will await the conclusion of their investigations, while also suggesting that a further election could be held specifically on whether to restart the reactors.[592] As of 1 July 2020, there is no indication as to when the Niigata investigation committees will conclude their work or what the governor's strategy will be.

As recent WNISRs have reported, the mayor of Kashiwazaki, Masahiro Sakurai, on 1 January 2017, announced that, as a condition for allowing restart of Units 6 and 7, TEPCO must propose a decommissioning plan by 2019 for at least one reactor from Units 1–5 (with no upward limit on the number of these reactors to be permanently shuttered).[593] The mayor suggested it was inevitable to scale down the plant, "Considering the Fukushima nuclear accident, seven reactors are too many."[594] The mayor extended his position on 25 July 2017, when he agreed to the restart of Units 6 and 7 but on the condition that TEPCO within two years "presents a plan to decommission the remaining five…"[595] The demand was made in the mayor's first meeting with TEPCO's new president, Tomoaki Kobayakawa, where June 2019 was set as a date when TEPCO would provide a plan. However, in the end, TEPCO did not meet with mayor Sakurai until 26 August 2019, at which company President Tomoaki Kobayakawa announced that they would consider plans to decommission one or more reactors at Kashiwazaki Kariwa within five years of restart of Units 6 and 7.[596]

At the meeting TEPCO presented a short briefing that outlined its approach in which the company restated that they consider Kashiwazaki Kariwa units 1–5 as necessary to meet an obligation of reaching the national target for non-fossil fuel generation.[597] This, "future desired power-source composition" was to comply with the fifth national Strategic Energy Plan of achieving about 40 percent of total generated electricity using non-fossil power sources by 2030. TEPCO assured that if they are able to secure sufficient renewable energy over the coming few years then steps will be taken for decommissioning.

TEPCO in recent years have communicated their intention to invest in renewables to make it a core area of their business, but the scale of growth and timeframe remains unclear. Making a link between future installed renewable capacity and decommissioning of Kashiwazaki Kariwa reactors would suggest that TEPCO are not yet ready to admit that a number of reactors at the site are not likely to operate again.

591 - Kentaro Hamada and Osamu Tsukimori, "Niigata governor's plans may upend TEPCO's nuclear restarts, restructuring", *Reuters*, 9 June 2017, see https://www.reuters.com/article/us-japan-nuclear-tepco-idUSKBN1900OR, accessed 27 April 2019.

592 - *The Asahi Shimbun*, "LDP-backed candidate wins governor's race in Niigata", 11 June 2018, see http://www.asahi.com/ajw/articles/AJ201806110049.html, accessed 20 May 2020.

593 - Niigata-Nippo, "Mayor Kashiwazaki asks TEPCO for decommissioning one of Units 1 to 5", 6 January 2017 (in Japanese) see http://www.niigata-nippo.co.jp/news/national/20170601327254.html, accessed 25 May 2018.

594 - *The Mainichi Shimbun*, "Mayor to link reactor decommissioning to restarting 2 others at same TEPCO plant", 2 June 2017, see https://mainichi.jp/english/articles/20170602/p2a/00m/0na/002000c, accessed 28 May 2020.

595 - *The Asahi Shimbun*, "Mayor: TEPCO's Niigata plant must close 5 reactors", 26 July 2017 (in Japanese), see http://www.asahi.com/ajw/articles/AJ201707260037.html, accessed 28 May 2020.

596 - *The Asahi Shimbun*, "EDITORIAL: Put state in charge of TEPCO's plan for reactor restarts", 10 September 2019, see http://www.asahi.com/ajw/articles/AJ201909100038.html, accessed 20 May 2020.

597 - TEPCO Holdings Ltd, "Kashiwazaki-Kariwa Nuclear Power Plant Reoperation and Decommissioning Basic Concept", 26 August 2019 (in Japanese), see https://www.tepco.co.jp/press/release/2019/pdf3/190826j0101.pdf, accessed 20 May 2020.

In January 2019, TEPCO, in partnership with global wind energy leader Orsted, launched its first commercial offshore wind project at Choshi off the coast of Chiba.[598] In September 2019, TEPCO announced that it was aiming for 370 MW of installed capacity by 2024 at the Choshi site.[599] Each of the Kashiwazaki Kariwa Units 1–5 have a power rating of 1,067 MW, for a total of 5.3 GW. Assuming a possible restart of Units 6 and 7 in 2022, a decision on decommissioning of other units within five years could see a significant increase in TEPCO's renewables portfolio. With a successful and rapid offshore wind development, it is possible that TEPCO will install sufficient GW of offshore wind to replace one or more units at Kashiwazaki Kariwa. The current Basic Energy Plan projects 10 GW of offshore wind by 2030. How much of this will be TEPCO/Orsted capacity remains to be seen but it could be substantial. However, the wider problem is the lack of ambition for renewables growth, including offshore wind, within the current Basic Energy Plan.

At the local level in Niigata, TEPCO is seeking to secure early approval for restart while offering the prospect of an earlier decommissioning schedule. It is, however, also aiming to influence the national Government. The current business plan of TEPCO was agreed with the Abe administration and is based on all seven reactors at Kashiwazaki Kariwa restarting during the early to mid 2020s. While that plan lacks credibility,[600] it aims to signal to the Government that by restarting reactors its financial viability is being restored.[601]

Following a meeting between the mayor of Kashiwazaki and TEPCO's president in December 2019, it was reported that the mayor had given his basic approval to TEPCO's proposed basis for decommissioning of one or more of its reactors.[602] On the basis of the plan's progress the mayor will decide on whether to approve restart for Units 6 and 7. The mayor stated that this did not mean he has accepted the restart of the reactors. After the meeting TEPCO's president stated that he believes the mayor broadly agrees to TEPCO's plans to restart Units 6 and 7.

The Niigata citizens' administrative lawsuit against the Kashiwazaki Kariwa reactor restarts remains ongoing, with earthquake risks a major focus. There are multiple seismic fault lines in the area of the Kashiwazaki Kariwa site, including large-scale submarine active faults, with four main ones, three of which run along either edge of the Sado Basin, a depression between Sado Island and mainland Kashiwazaki.[603] The seismic risks at the Kashiwazaki Kariwa site remain unresolved despite assurances from TEPCO that retrofits are sufficient to meet seismic hazards.

598 - *Offshore WIND*, "TEPCO Ponders 1GW Offshore Wind Farm in Japan", 9 January 2019, see https://www.offshorewind.biz/2019/01/09/tepco-ponders-1gw-offshore-wind-farm-japan/; and *Offshore WIND*, "TEPCO and Ørsted Form Offshore Wind Pact, First Stop Japan", 18 January 2019, see https://www.offshorewind.biz/2019/01/18/tepco-and-orsted-form-offshore-wind-pact-first-stop-japan/; both accessed 20 May 2020.

599 - *Offshore WIND*, "TEPCO Floats 370MW Choshi Offshore Wind Farm Plan", 5 September 2019, see https://www.offshorewind.biz/2019/09/05/tepco-floats-370mw-choshi-offshore-wind-farm-plan/, accessed 20 May 2020.

600 - Shaun Burnie, "TEPCO'S Atomic Delusion", Greenpeace Japan, 25 June 2018, see https://storage.googleapis.com/planet4-japan-stateless/2019/08/3d2e8976-atomic_delusion.pdf, accessed 20 May 2020.

601 - *The Asahi Shimbun*, "EDITORIAL: Put state in charge of TEPCO's plan for reactor restarts", 10 September 2019, see http://www.asahi.com/ajw/articles/13058650, accessed 20 May 2020.

602 - *Jiji Press*, "Mayor approves TEPCO's N-reactor decomissioning plan", as published by *The Japan Times*, 9 November 2019, see https://the-japan-news.com/news/article/0006171647, accessed 20 May 2020.

603 - Katsuhiko Ishibashi and Mitsuhisa Watanabe, "Earthquakes and Ground Condition Just how safe is the Kashiwazaki-Kariwa Nuclear Power Plant?", CNIC, Nuke Info Tokyo No. 123, March/April 2008, see http://www.cnic.jp/english/newsletter/pdffiles/nit123.pdf, accessed 20 May 2020.

There have been steps forward and further delays in plans for the restart of the 1100-MW BWR **Tokai-2**, owned by Japan Atomic Power Company (JAPC). The reactor, located in Ibaraki Prefecture and connected to the grid in 1978, is the closest to the Tokyo metropolitan area. It was shut down on 11 March 2011. Japan Atomic Power announced on 28 January 2020 that engineering and construction works at the plant, including a 1.7 km long coastal levee, were taking longer than anticipated.[604] On 22 February 2019, JAPC announced its intention to proceed with the restart of Tokai-2.[605] The target date is January 2023. This followed a 7 November 2018 unanimous decision by NRA commissioners to approve an additional 20 years of operation.[606]

As reported in WNISR2019, local approval is more complicated for Tokai-2 than other sites in Japan as the power plant is covered by an agreement between the utility and municipalities. There is strong public opposition within Ibaraki to restart of Tokai-2.[607] JAPC must obtain restart consent for Tokai-2 from six municipalities — Tokai village and the cities of Hitachi, Hitachinaka, Hitachiota, Mito and Naka—as well as the prefectural government of Ibaraki before it can restart the unit. About 940,000 people live in 14 municipalities within a 30-kilometer (18.6-mile) radius of the Tokai plant and the facility is closer to the Tokyo area than any other nuclear plant.

More positively for the utility, on 28 October 2019, the board of TEPCO approved the financing of ¥220 billion (US$2 billion) for the Tokai-2 reactor.[608] Explaining the decision, Rikuo Ohtsuki, a managing executive officer at TEPCO stated "We have reached a conclusion that we can expect the Tokai No. 2 nuclear plant to be a source of power that helps provide inexpensive and stable electricity that emits less carbon dioxide to customers."[609] TEPCO's contribution is expected to cover around 60 percent of the current estimate cost. The decision is particularly controversial as TEPCO is effectively a state-owned utility and technically bankrupt following 3/11. JAPC is unique in Japan as it is a utility owned by all other nuclear utilities. A framework plan for financing Tokai-2 has been agreed by TEPCO and Tohoku Electric Power Company.[610] They both have contracts for the electricity generated at the reactor. KEPCO, Chubu Electric Power Company and Hokuriku Electric Power Company have also agreed to contribute to the reactor costs.

The securing of financing for retrofits has been one of the biggest challenges for JAPC, originally estimated at ¥174 billion (US$1.54 billion),[611] by March 2019, this was revised to ¥300 billion

604 - JAPC, "Tokai Nuclear Power Plant license About change of construction plan", Japan Atomic Power Company, 28 January 2020 (in Japanese), see http://www.japc.co.jp/news/press/2019/pdf/200128.pdf, accessed 29 May 2020.

605 - JAPC, "Revision of the Tokai Power Station and Tokai No. 2 Power Plant nuclear operator emergency plan", 22 February 2019, see http://www.japc.co.jp/news/press/2018/pdf/310222_1.pdf, accessed 28 May 2020.

606 - JAIF, "NRA Allows Tokai-2 to Be Operated for Sixty Years, a First for a BWR", 16 November 2018, see https://www.jaif.or.jp/en/nra-allows-tokai-2-to-be-operated-for-sixty-years-a-first-for-a-bwr/, accessed 28 April 2019.

607 - *The Asahi Shimbun*, "EDITORIAL: TEPCO needs to make its case for bailing out aging nuclear plant", 31 October 2019, see http://www.asahi.com/ajw/articles/AJ201910310032.html, accessed 21 May 2020.

608 - *The Asahi Shimbun*, "TEPCO to pour 220 billion yen into Tokai No. 2 nuclear plant", 29 October 2019, see http://www.asahi.com/ajw/articles/AJ201910290042.html, accessed 21 May 2020.

609 - Ibidem.

610 - *The Mainichi Shimbun*, "TEPCO, Tohoku Electric to give Japan Atomic financial boost to help restart reactor", 29 March 2018, see https://mainichi.jp/english/articles/20180329/p2a/00m/0na/015000c, accessed 21 May 2020.

611 - S&P Platts, "NRA approves Tokai-2 life extension", 7 November 2018.

(US$2.73 billion).[612] The company itself was incapable of funding the retrofits due to its dire financial straits as consequence of loss of revenue from electricity sales following reactor shutdowns, bad investment decisions in plans for the constructions of Tsuruga-3 and -4 (which were abandoned) and decommissioning costs related to its Tsuruga-1 and Tokai-1 reactors.[613]

Failure to secure financing for Tokai-2 would have taken JAPC one step closer to bankruptcy, with serious implications for other utilities. This represents one major reason why TEPCO and the other utilities have agreed to finance the reactor backfitting. The utility has only one other reactor, Tsuruga-2 in Fukui Prefecture. It has been in dispute with the NRA for the past years over the designation of an active seismic fault at the site, and there are currently no prospects for the reactor operating.

The utility in February 2020 indicated an envisaged restart date of December 2022 in its application to the NRA for pre-operational inspections. This had been widely criticized in the local community given that no approval had been granted and negotiations have not even formally commenced. In January 2020, the completion of construction works at the site was delayed to November and December 2022, with restart scheduled for the first half of 2023.[614] With likely additional cost escalations, the uncertainties in the latest construction schedule, and the complexities of overcoming opposition within Ibaraki and securing municipality approval, there remains major doubt about a 2023 restart for Tokai-2, by which time it will have been in LTO for 12 years.

Other reactors within the NRA review process continue to have multiple challenges. For example, Hokkaido Electric Power Company, the owner of the PWR **Tomari** nuclear plant, continues to be in dispute with the NRA over the status of a seismic fault line at the site. The utility claims that the fault has not been active for 400,000 years, whereas the NRA takes the position that there is no evidence that the fault was "not active within the past 120,000 years",[615] the latter is the time period which, if confirmed, would preclude restart of the reactor.

The risks from major seismic events was demonstrated when on 6 September 2018 a magnitude 6.7 earthquake struck the island of Hokkaido.[616] Thermal power plants shut down across the island, and the Tomari nuclear plant, including spent fuel pools, were reliant upon onsite emergency generators for a period of 10 hours.

Prospects for Nuclear Power

It is clear that nine years after 3/11, Japan's nuclear utilities have failed to overcome the multiple obstacles to restarting a major part of their nuclear fleet. Reflecting the negative state of the Japanese nuclear industry was the results of the JAIF 2018 Fact Finding Review released in

612 - *The Asahi Shimbun*, "TEPCO takes risk over soaring costs at Tokai nuclear plant", 15 March 2019, see http://www.asahi.com/ajw/articles/AJ201903150001.html, accessed 28 May 2020.

613 - Mitsunobu Ohishi, "Tokai II Nuclear Power Plant's 20 year extension: A story of economic inefficiency and passing the buck", Co-Representative of the class action lawsuit demanding an injunction on Tokai II, CNIC, 2 February 2018, see http://www.cnic.jp/english/?p=4044, accessed 28 April 2020.

614 - JAPC, 28 January 2020, op. cit.; and JAPC, "Fiscal 2020 Tokai Power Station / Tokai Daini Power Station's annual major business plans", 30 April 2020, see http://www.japc.co.jp/news/press/2020/pdf/200430.pdf, accessed 21 May 2020.

615 - *NW*, "NRA's restart review of Onagawa-2 'most progressed' official say", 15 May 2019.

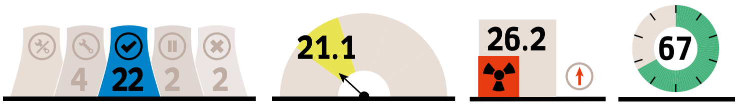
616 - *The Japan Times*, "Powerful M6.7 earthquake rocks Hokkaido, causing massive landslides; nine dead and 31 reported missing", 6 September 2018.

November 2019.[617] The survey covered the fiscal year 2018 (ended March 2019). Questionnaires were distributed to a total of 350 for-profit companies engaged in the nuclear power field, including JAIF's member companies, seeking information on their expenditures, sales and numbers of employees. As JAIF commented, "nuclear-related expenditures by electric power companies rose substantially by 12 percent from the previous year. By expenditure item, capital investment increased by 40 percent, and fuel and materials costs by 28 percent. (…) Regarding business sentiment in industries related to nuclear power, most survey respondents (responding in FY19) described theirs as 'bad' (80 percent). Those expecting it to be worse in one year (in FY20) increased from 10 percent in the previous survey to 24 percent."[618]

In terms of selecting a potential path to recovery, the most common answer was with 73 percent prioritizing consistent promotion of nuclear policy by the Government, with 53 percent stating restoration of public confidence in nuclear power, and 58 percent early restarts of reactors and stable operation. Utilities are far from attaining their wishes. As polling continues to show,[619] as well as numerous ongoing lawsuits, there is no shift in public opinion in favor of nuclear reactor operations; and with multiple shutdowns in 2020 there is continuing instability in nuclear reactor operations.

In terms of that public opposition and technical challenges, a report by Fitch Solutions in February 2020 noted that, "We expect these factors will continue to challenge Japan's push for nuclear restarts, prompting our more bearish outlook on nuclear power generation which we now expect will reach approximately 85.4 TWh by 2029, accounting for 8.4% of the total power mix."[620] That would be a very modest recovery a decade from now, not even a percentage point above the nuclear contribution in 2019. And yet, it might turn out overly optimistic a few years from now.

SOUTH KOREA FOCUS



On the Korean Peninsula, South Korea (Republic of Korea) operates 22 reactors, with one reactor (Hanbit-4) remaining in Long-Term Outage (LTO) and one reactor (Hanbit-3) meeting the LTO criteria as of July 2020. Four reactors are under construction as of 1 July 2020. In June 2018, the commercial operation of Wolsong-1 was "terminated",[621] and the Nuclear Safety and Security Commission (NSSC) on 24 December 2019 formally passed the bill for its closure.[622]

617 - JAIF, "JAIF Releases Results of Fact-Finding Survey of Japanese Nuclear Industry for Fiscal 2018", Press Release, 27 November 2019, op. cit.

618 - Ibidem.

619 - JAERO, "2019 poll results", Japan Atomic Energy Relations Organization, March 2020 (in Japanese), see https://www.jaero.or.jp/data/01jigyou/pdf/tyousakenkyu2019/r2019.pdf, accessed 20 July 2020.

620 - *Asian Power*, "Japan to miss nuclear targets amidst industry headwinds", 24 February 2020, see https://asian-power.com/regulation/news/japan-miss-nuclear-targets-amidst-industry-headwinds, accessed 18 May 2020.

621 - KHNP, "Nuclear Power Operation - Plant Status", 31 December 2018, see http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101, accessed 3 June 2020.

622 - NSSC, "The 112th Meeting of the Commission Was Held", 24 December 2019, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?pageNo=4&pagePerCnt=10&MENU_ID=90&CONTENTS_NO=&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45891&USER_NAME=&TEL_NO=&WRITER_DI=&_csrf=&SEARCH_FLD=&SEARCH, accessed 7 June 2020.

The Government is currently reviewing a new draft energy plan which, if implemented, will see further reduction in installed nuclear capacity, with a consequences of generating only 10 percent of the nation's electricity in 2034[623] compared to 26.2 percent in 2019 and 53.3 percent in 1987. The further reduction of nuclear capacity, combined with a commitment to phase out coal and increased expansion of renewable energy reflects the continuing electoral success of the ruling Democratic Party and President Moon Jae-in.[624] In mid-April 2020, the party had its largest win in National Assembly elections, with a manifesto commitment to a Green New Deal aimed at delivering net zero carbon emissions by 2050, the first by a nation in East Asia.[625]

South Korea's nuclear fleet, owned by Korea Hydro & Nuclear Power Company (KHNP), is located at the Hanbit, Hanul, Kori and Wolsong sites. Nuclear power provided 138.6 TWh in 2019, compared with 127 TWh in 2018, a year-on-year increase of 9.1 percent.

Permanent Closure

The NSSC formally passed the bill for the permanent closure of Wolsong-1 on 24 December 2019.[626] The decision has met with protests from the main opposition Liberal Democratic Party (LDP) and the labor union of KHNP, which have launched legal action against NSSC and its members.[627] Following the closure of Wolsong-1, the seven reactors that are now planned to be closed just prior to reaching their 40-year operating lifetime total 6.6 GW of capacity and are Kori-2 in 2023, Kori-3 in 2024, Kori-4 and Hanbit-1 in 2025, and Hanbit-2 in 2026, Hanul-1 in 2027 and Hanul-2 in 2028. Three reactors are scheduled to be closed as they reach their 30-year lifetime: Wolsong-2 in 2026, Wolsong-3 in 2027 and Wolsong-4 in 2029 (see Table 8).[628]

623 - *Yonhap*, "S. unveils draft plan to foster renewable energy", 8 May 2020, see https://en.yna.co.kr/view/AEN20200508002200320, accessed 1 August 2020.

624 - *Hankyoreh*, "Democratic Party's sweeping victory shows the public supports for Moon administration", 16 April 2020, see http://english.hani.co.kr/arti/english_edition/english_editorials/937401.html; and Tim Shorrock, "Electoral Triumph Spurs Green New Deal in South Korea", *The Nation*, 1 May 2020, see https://www.thenation.com/article/world/south-korea-elections-climate/, both accessed 4 June 2020.

625 - *Yonhap*, "S. Korea to include green projects in 'New Deal' plan", as published by *The Korea Herald*, 20 May 2020, see http://www.koreaherald.com/view.php?ud=20200520000815; and Tim Ha, "In East Asian first, South Korea announces ambitions to reach net zero by 2050", *Eco-business*, 17 March 2020, see https://www.eco-business.com/news/in-east-asian-first-south-korea-announces-ambitions-to-reach-net-zero-by-2050/; both accessed 4 June 2020.

626 - NSSC, "The 112th Meeting of the Commission Was Held", 24 December 2019, op. cit.

627 - *NEI*, "Permanent closure of South Korea's Wolsong 1 sparks protests", 2 January 2020, see https://www.neimagazine.com/news/newspermanent-closure-of-south-koreas-wolsong-1-sparks-protests-7581947; and *Business Korea*, "Firestorm Erupts over Permanent Shutdown of Wolsong Nuclear Plant Unit 1", 30 December 2019, see http://www.businesskorea.co.kr/news/articleView.html?idxno=39649, both accessed 3 June 2020.

628 - MOTIE, "The 8th Basic Plan for Long-term Electricity Supply and Demand (2017-2031)", Ministry of Trade, Industry and Energy, 2017, see https://www.kpx.or.kr/www/downloadBbsFile.do?atchmnflNo=30051, accessed 3 June 2020.

Table 8 · Status of Nuclear Reactor Fleet in South Korea (with scheduled closure dates)

Reactor	Type	MW	Grid connection	Expected Closure
Kori-2	PWR	640	1983	2023
Kori-3	PWR	1011	1985	2024
Kori-4	PWR	1012	1985	2025
Hanbit-1	PWR	995	1986	2025
Hanbit-2	PWR	988	1986	2026
Wolsong-2	PHWR	606	1997	2026
Wolsong-3	PHWR	630	1998	2027
Hanul-1	PWR	966	1988	2027
Hanul-2	PWR	967	1989	2028
Wolsong-4	PHWR	609	1999	2029
Hanbit-3	PWR	986	1994	
Hanbit-4	PWR	970	1995	
Hanbit-5	PWR	992	2001	
Hanbit-6	PWR	993	2002	
Hanul-3	PWR	997	1998	
Hanul-4	PWR	999	1998	
Hanul-5	PWR	998	2003	
Hanul-6	PWR	997	2005	
Shin-Kori-1	PWR	996	2010	
Shin-Kori-2	PWR	996	2012	
Shin-Kori-3	PWR	1416	2016	
Shin-Kori-4	PWR	1418	2019	
Shin-Wolsong-1	PWR	997	2012	
Shin-Wolsong-2	PWR	993	2015	

Source: MOTIE, 2017

Notes:

PWR: Pressurized Water Reactor; PHWR: Pressurized Heavy-Water Reactor.

Containment Liner Plate Corrosion

In recent years, there have been extended outages of South Korea's nuclear reactors. The principle reason for this has been that out of the 24 reactors South Korea operated (prior to startup of Shin-Kori-4 in 2019) 21 were found to have corrosion in the Containment Liner Plates (CLP) or voids in the concrete structure.[629]

629 - Charles Lee, "South Korea completing safety checks on all reactor containment structures", *Nucleonics Week*, 9 May 2019.

> Reactor containment-buildings in Korea are insulated with a CLP of six millimeters in diameter, and then concrete 1.2 meters in diameter thick. As the U.S. NRC noted in 1997: Any corrosion (metal thinning) of the liner plate could change the failure threshold of the liner plate under a challenging environmental or accident condition. Thinning changes the geometry of the liner plate, creating different transitions and strain concentration conditions. This may reduce the design margin of safety against postulated accident and environmental loads.[630]

Under nuclear regulation evidence of structural deterioration that could affect the structural integrity or leak-tightness of metal and concrete containments must be corrected before the containment can be returned to service. Corrosion of a liner plate can occur at a number of places where the metal is exposed to moisture, or where moisture can condense (behind insulation) or accumulate. Corrosion damage of CLPs historically has primarily been either the result of embedded foreign material (e.g. wood) in contact with the liner resulting in corrosion or inside initiated corrosion resulting from coating failures or moisture barrier degradation. The corrosion repair has consisted of removal of the damaged liner section and embedded foreign material, grouting the resulting void, and replacing the liner plate section.[631]

Root cause analysis of the causes of CLP corrosion reported by Korea Institute of Nuclear Safety (KINS) were predominately due to exposure to moisture (environment), as well as the presence of foreign debris.[632]

During 2019, CLP issues continued to be detected at reactors undergoing inspection leading to extended outages. Hanul-2, which had been undergoing periodic inspection since October 2019, was found to have 2,116 spots short of standard thickness. However, the NSSC confirmed that the integrity of the CLPs had been maintained through the repair work and integrity assessments. In addition, 53 locations of the CLPs which were suspected of having voids in the concrete were cut and inspected, and as a result, one spot was found to have a void. The NSSC required the licensee to repair the spot, prior to restart of the reactor in early February 2020.[633] Hanul-4 also was found to have 180 spots thinned to 5.4 mm or less due to surface corrosion caused by moisture in the gap, but no voids were detected.[634] The reactor was permitted to restart in February 2020 following completion of repair work and safety assessments. Hanul-5 was inspected in September 2019 and three spots in the CLPs were below regulatory requirements. A total of 93 locations of the CLPs were suspected of having voids in the concrete were cut and inspected, and as a result, two spots were found. After repair and

630 - Office of Nuclear Reactor Regulation, "Information Notice No. 97-10: Liner Plate Corrosion in Concrete Containments", U.S.NRC, 13 March 1997, see https://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1997/in97010.html, accessed 7 June 2019.

631 - Jason P. Petti, Dan Naus et al., "Nuclear Containment Steel Liner Corrosion Workshop: Final Summary and Recommendation Report", Sandia National Laboratories, operated for the U.S. Department of Energy, Report SAND2010-8718, July 2011, see https://www.nrc.gov/docs/ML1121/ML112150012.pdf, accessed 7 June 2019.

632 - Yonglak Paek, Sangyun Kim, Euisik Yoon and Hun Cha, "Introduction of Containment Liner Plate (CLP) Corrosion", Korea Institute of Nuclear Safety, Transactions of the "Korean Nuclear Society Spring Meeting", 17–18 May 2018, see https://www.kns.org/files/pre_paper/39/18S-189%EB%B0%B1%EC%9A%A9%EB%9D%BD.pdf, accessed 3 June 2020.

633 - NSSC, "The NSSC Approves the Criticality of Hanul Unit 2 During Periodic Inspection", 4 February 2020, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?pageNo=3&pagePerCnt=10&MENU_ID=90&CONTENTS_NO=&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45902&USER_NAME=&TEL_NO=&WRITER_DI=&_csrf=&SEARCH_FLD=&SEARCH=, accessed 3 June 2020.

634 - NSSC, "The NSSC Approves the Criticality of Hanul Unit 4", 21 February 2020, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?pageNo=3&pagePerCnt=10&MENU_ID=90&CONTENTS_NO=&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45907&USER_NAME=&TEL_NO=&WRITER_DI=&_csrf=&SEARCH_FLD=&SEARCH, accessed 3 June 2020.

safety assessment, the NSSC granted restart approval to KHNP in December 2019.[635] KHNP is required to submit its structural integrity assessment of the concrete voids found in the containment building of the reactors to the NSSC, which will then require a technical review by KINS, a technical support organization, and independent verification by the Korea Concrete Institute.[636]

As of 1 July 2020, Hanbit-3 and -4 remain shut down due to CLP. On 7 July 2019, Korean broadcaster *MBC* reported that KHNP had confirmed 94 holes between the steel plate and concrete inside the reactor building of Hanbit-3 and 96 holes in Hanbit-4. KHNP, according to *MBC*, explained that the holes found are up to 90 cm in size, but there would be "no problem with the structural stability of the containment."[637] Hanbit-4 has been shut down since May 2017 and remains in LTO status as of 1 July 2020, and Hanbit-3 met the LTO criteria at this date.

Power Surge

In October 2019, KHNP's Hanbit-1 returned to service after it was manually tripped following a power surge on 10 May 2019.[638] The reactor had been in maintenance outage since 2018 but had been authorized to restart. The NSSC reported thermal power had exceeded the 5 percent limit set in the reactor license Technical Specifications, reaching 18 percent.[639] This caused the temperature of the reactor coolant to rise rapidly, along with the steam generator level. The rising level of the steam generator tripped the main feed water pump, activating the auxiliary water pump. The NSSC reported that KHNP did not immediately shut down the reactor even though the thermal output of the reactor exceeded the limit during a test. In addition, the control rods were operated by a person who does not hold a Reactor Operator's license (RO). The reactor was eventually shut down 12 hours after the initial event.[640] NSSC confirmed that "the main cause of the event is a human error that involved a violation of the relevant laws and procedures and operation of inexperienced operators".[641]

635 - NSSC, "The NSSC Approves the Criticality of Hanul Unit 5 During Periodic Inspection and Conducts Power Ascension and Other Remaining Tests", 23 December 2019, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?pageNo=4&pagePerCnt=10&MENU_ID=90&CONTENTS_NO=&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45890&USER_NAME=&TEL_NO=&WRITER_DI=&_csrf=&SEARCH_FLD=&SEARCH, accessed 3 June 2020.

636 - NSSC, "Regarding Concrete Voids of Containment Buildings of Hanbit Unit 3 and 4, the NSSC Will Verify Structural Integrity Objectively and Transparently", 12 March 2020, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?pageNo=2&pagePerCnt=10&MENU_ID=90&CONTENTS_NO=&SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45909&USER_NAME=&TEL_NO=&WRITER_DI=&_csrf=&SEARCH_FLD=&SEARCH, accessed 3 June 2020.

637 - *MBC News*, "190 hatch holes in the containment building of Hanvit 3. 4", 7 July 2019 (in Korean), see https://n.news.naver.com/article/214/0000961974, accessed 19 July 2019.

638 - NSSC, "The NSSC to Start Inspection of Hanbit Unit 1 After Manual Shutdown", 10 May 2019, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45422&MENU_ID=90&CONTENTS_NO=1, accessed 5 June 2020.

639 - NSSC, "The NSSC to Expand the Special Inspection on Manual Shutdown of Hanbit Unit 1", 20 May 2019, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=45431&pager.offset=10&board_no=501, accessed 3 June 2020.

640 - Choi Ha-yan, "Nuclear reactor kept running for 12 hours after it should have been shut down", *Hankyoreh*, 21 May 2019, see http://english.hani.co.kr/arti/english_edition/e_business/894763.html, accessed 3 June 2020.

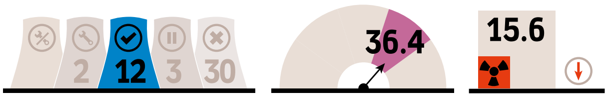
641 - NSSC, "The NSSC Discussed and Passed the Result of the Special Investigation of the Hanbit Unit 1 and the Plan", Press Release, 9 August 2019, see https://www.nssc.go.kr/en/cms/FR_BBS_CON/BoardView.do?SITE_NO=3&BOARD_SEQ=1&BBS_SEQ=45626&MENU_ID=90&CONTENTS_NO=1, accessed 27 August 2020.

Energy Policy

In December 2017, the Government approved the 8th Basic Plan for long-term Electricity supply and demand (BPE), which marked a major shift in overall energy policy, while confirming the gradual nuclear phase-out road-map announced in October 2017.[642] Over more than three decades the energy policy of successive South Korean Governments had been premised on the continued expansion of nuclear power, including for example a target of 41 percent by 2030 (2008 first National Energy Basic Plan for 2008–2030) and in 2011, when Korea Electric Power Corporation (KEPCO) proposed 43 GW of nuclear capacity by 2035.

According to the May 2020 draft energy plan, 11 reactors with a combined capacity of 9.5 GW will be closed by 2034.[643] The plan, known as the "Long-Term Basic Blueprint for Power Supply over 2020–2034", is expected to be finalized during summer 2020, following discussions in the National Assembly and public hearings. Overall, the Government plan is to reduce dependence on nuclear and fossil fuel from the 46.3 percent in 2020 to 24.8 percent by 2034 while at the same time expanding reliance on renewables from 15.1 percent to 40 percent.[644] Under the current draft, the number of units would peak at 26 in 2024, and by 2034 there would be 17 reactors still operating with a total of 19.4 GW installed nuclear capacity and generating 10 percent of South Korea's electricity. This compares with 25 reactors in 2020 and 23.3 GW and 19.2 percent of the nation's electricity. A total of 5.6 GW of new nuclear capacity—Shin-Hanul-1 and -2, and Shin-Kori-5 and -6—are scheduled to begin commercial operation between 2020–2024.

UNITED KINGDOM FOCUS



In 2019, the United Kingdom operated 12 reactors, which provided 56 TWh, a decline over the previous year. Three reactors, Dungeness B-1 and B-2, as well as Hunterston B-1 entered the LTO category. Nuclear power provided 14 percent of power, down from a maximum of 26.9 percent in 1997. The average age of the U.K. fleet stands at 36.4 years (see Figure 41).

Power demand continued to fall in the U.K., by 2.8 percent to reach 324 TWh, a trend that started in 2010. The use of renewables increased to 37 percent of consumption in 2019, up from with 33 percent in 2018, representing now more than double the supply from nuclear power. The other major event over the past few years has been the decline in the use of coal, which produced just 7 TWh in 2019.[645]

A total of 30 power reactors have been permanently closed, all 26 Magnox reactors, both fast reactors, a prototype Advanced Gas-cooled Reactor (AGR) at Windscale and a prototype Steam Generating Heavy Water Reactor (SGHWR) at Winfrith. The U.K.'s seven second-generation

642 - Se Young Jang, "South Korea's Nuclear Energy Debate", *The Diplomat*, as published by Carnegie Endowment for International Peace, 26 October 2017, see http://carnegieendowment.org/2017/10/26/south-korea-s-nuclear-energy-debate-pub-73561, accessed 3 June 2020.

643 - *Nucleonics Week*, "South Korea would cut nuclear capacity 20% by 2034 under draft energy plan", *S&P Platts*, 21 May 2020.

644 - *Pulse*, "Seoul keeps to plan of weaning the country off nuclear fuel, expand renewables to 40%", *Maeil Business News Korea*, 8 May 2020, see https://pulsenews.co.kr/view.php?year=2020&no=471886, accessed 4 June 2020.

645 - BEIS, "UK electricity, generation, trade and consumption, October to December 2019", U.K. Government, 30 April 2020, see https://www.gov.uk/government/statistics/electricity-section-5-energy-trends, accessed 21 May 2020.

nuclear stations, each with two AGRs, are all operating past the end of their original 25-year design lives. These are expected to close between 2023 and 2030, while the country's only Pressurized Water Reactor (PWR), at Sizewell B, is scheduled to operate until at least 2035.[646]

EDF Energy, a wholly owned subsidiary of French state-controlled utility EDF, is the majority owner of the company Lake Acquisitions that owns these reactors. Centrica has a minority share (20 percent) in Lake Acquisitions. However, Centrica has been trying to sell its stake since 2013; the 2019 annual report says, "we re-affirmed our strategic direction back towards the customer and our desire to exit nuclear".[647] EDF has been trying to reduce its stake to 51 percent since 2016 but equally without any takers.

Managing reactors as they age is a constant problem for any technology design and the AGRs are no exception. In recent years problems with the core's graphite moderator bricks have raised concerns. In particular, keyway root cracks (KWRC), exceeding the number the Office for Nuclear Regulation (ONR) previously deemed permissible, have been found at one of the Hunterston B reactors. 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 on 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 limit of erosion that the ONR has set. With age, the graphite bricks also distort and may eventually compromise the operation of the safety control rods. ONR has said these issues are likely to be the life-limiting factor for the AGRs, as it is not possible to replace the graphite bricks.[648]

In March 2018, during a scheduled outage, EDF discovered a higher number of keyway root cracks in the older of the two reactors than was predicted by its computer models in 2016 when the reactor underwent its statutory 10-year Periodic Safety Review. Then in May 2018, EDF announced that Hunterston B-1's current shutdown, previously expected to be completed in May 2018, would be extended for further investigation and revised modeling, with the intention of restarting the reactor before the end of 2018. In late December 2018, EDF stated that they have

> ...observed around 100 keyway root cracks in Reactor 3 [Hunterston B-1]. This is from the inspection of just over a quarter of the reactor. Using modeling to project the number of cracks across the whole reactor our best estimate of the current number of cracks is around 370. This takes the core over the operational limit of 350 contained in the existing safety case for that period of operation.[649]

In December 2018, EDF estimated that Hunterston B-1 would be restarted in March 2019; however this deadline was revised several times, and, as of early July 2020, the reactor was still offline, with restart scheduled for late August 2020.[650] The reactor met the LTO criteria in

646 - EDF Energy, "Reactor Lifetimes—Nuclear Lifetime Management", Undated, see https://www.edfenergy.com/energy/nuclear-lifetime-management, accessed 21 May 2020.

647 - Centrica, "Annual Report and Accounts 2019", March 2020, see https://www.centrica.com/investors/annual-report-2019/, accessed 21 May 2020.

648 - ONR, "Graphite core ageing", Updated 6 August 2019, see http://www.onr.org.uk/civil-nuclear-reactors/graphite-core-ageing.htm, accessed 3 August 2020.

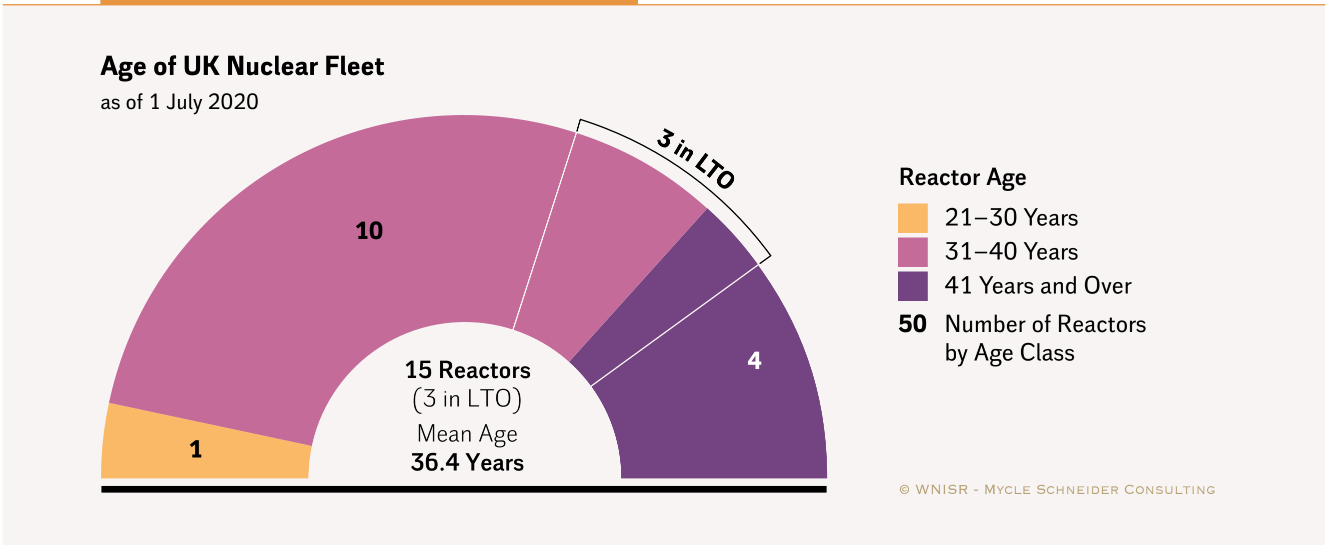
649 - EDF Energy, "Hunterston Graphite Inspections – December 2018", Press Release, December 2018, see https://www.edfenergy.com/sites/default/files/hunterston_december_update_final.pdf, accessed 21 May 2020.

650 - EDF Energy, "Letter to the Hunterston Site Stakeholder Group - 2 July 2020", 2 July 2020, see https://www.edfenergy.com/media-centre/news-releases/letter-hunterston-site-stakeholder-group-2-july-2020, accessed 14 July 2020.

July 2020, and is considered as LTO since last production in March 2018. Hunterston B-2 was shut for inspection in October 2018, and in August 2019 ONR granted EDF Energy permission to restart the reactor for the next period of operation (about 4 months)[651] before it was shut again in December 2019. After several delays, as of early July 2020, its restart is scheduled for September 2020.[652]

In July 2019, the ONR's Annual Report stated that Hunterston B were in an "enhanced level of regulatory attention", rather than routine. This was because assessment of the cracks required "substantial additional effort." Part of the reason for the delay is that ONR revealed in a technical report that 58 fragments had broken from the graphite bricks and there was "significant uncertainty", over the risk of these blocking the fuel channels. The ONR would require more robust arguments before agreeing to the restart of the reactors.[653]

Figure 41 · Age Distribution of the U.K. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2020

Age-related problems have also been found at similar reactors at Dungeness-B, with Unit 2 closed for what was supposed to be a 12-week outage in August 2018 and then Unit 1 for "common statutory outage work", in September 2018, with both expected to restart in April 2019. However, the outage has been extended, with current restart dates for the units set at September 2020.[654] Concerns have been raised that life-limiting cracking will be found at the other AGRs; and in May 2020 it was revealed that the ONR in its 10-year review had estimated that "The predicted timescales for onset of keyway root cracking has changed from 2028 to mid-2022."[655] Consequently, the future of many of the AGRs is being questioned by investors,

651 - ONR, "Hunterston B Reactor 4", 20 August 2019, see http://news.onr.org.uk/2019/08/hunterston-b-reactor-4/, accessed 6 June 2020.

652 - EDF Energy, "Letter to the Hunterston Site Stakeholder Group - 2 July 2020", 2 July 2020, op. cit.

653 - Rob Edwards, "Safety fears as Hunterston's cracked nuclear reactors start to crumble", *The Ferret*, 17 October 2019, see https://theferret.scot/hunterston-graphite-debris-nuclear/, accessed 21 May 2020.

654 - EDF Energy, "Dungeness B - Site Stakeholder Group Report June 2020", 2 June 2020, see https://www.edfenergy.com/media-centre/news-releases/dungeness-b-site-stakeholder-group-report-june-2020, accessed 3 June 2020.

655 - Rob Edwards, "Torness nuclear reactors predicted to start cracking in 2022", *The Ferret*, 6 May 2020, see https://theferret.scot/torness-nuclear-reactors-cracking-2022/, accessed 21 May 2020.

who see ongoing outages and higher maintenance costs not outweighing the economic benefits of a possible additional couple of years of operation.[656] Both Dungeness-B reactors met the LTO criteria in July 2020, and are therefore considered in LTO since their respective last power production.

The development of new nuclear reactors in the U.K. has been slow and gradually grinding to a halt. The current development cycle was "officially launched" in 2006, when then Prime Minister Tony Blair stated that nuclear issues were "back on the agenda with a vengeance".[657] In July 2011, the Government released the National Policy Statement (NPS) for Nuclear Power Generation.[658] The eight "potentially suitable" sites considered in the document for deployment "before the end of 2025" are exclusively current or past nuclear power plant sites in England or Wales, except for one new site, Moorside, adjacent to the fuel-chain facilities at Sellafield. Northern Ireland and Scotland are not included. The Scottish Government is opposed to new-build and have reiterated their "continued opposition to new nuclear stations, under current technologies. The economics of these stations are prohibitive, especially given the falling costs of renewable and storage technologies".[659]

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[660] announced updates to the October 2013 provisional agreement of commercial terms of the deal for the £16 billion (US$19.5 billion) overnight cost of construction of Hinkley Point C (HPC). The estimated price of construction has since risen and as of 2017 stood at £$_{2015}$19.6 billion (US$$_{2015}$25.3 billion), up from the £201518 billion (US$$_{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."[661] Then 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 is now £23.2 billion (US$28.8 billion).[662] EDF stated

656 - Phil Chaffee, "Restive Investors Challenge EDF on UK's Troubled AGRs.", *NIW*, 28 February 2020.

657 - *BBC*, "Blair backs nuclear power plans", 16 May 2006, see http://news.bbc.co.uk/1/hi/uk_politics/4987196.stm, accessed 21 May 2020.

658 - DECC, "National Policy Statement for Nuclear Power Generation", Department of Energy & Climate Change, U.K. Government, July 2011.

659 - Scottish Government, "Scottish Energy Strategy: The future of energy in Scotland", 20 December 2017, see https://www.gov.scot/publications/scottish-energy-strategy-future-energy-scotland-9781788515276/, accessed 21 May 2020.

660 - DECC, "Hinkley Point C to power six million UK homes", Department of Energy & Climate Change, 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 21 May 2020.

661 - 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 21 May 2020.

662 - EDF Energy, "Update on Hinkley Point C project", EDF, 25 September 2019, see https://www.edfenergy.com/media-centre/news-releases/update-on-hinkley-point-c-project, accessed 21 May 2020.

Figure 42 · The Hinkley Point C Construction Site

Photo: EDF Energy, 2019.

Note: The Hinkley Point C site six months after the official construction start (beginning of concreting of the base slab of the reactor building) of Unit 1 and six months before construction start of Unit 2. The term "construction start" does not appear to reflect any reality anymore.

that "management of the project remains obilized to begin generating power from Unit 1 at the end of 2025", which is not a clear statement of confidence in the current schedule.[663]

The IAEA dates formal start of construction for a nuclear power plant as the pouring of first structural concrete for the base slab of the reactor building and this occurred for the first unit at HPC on 11 December 2018 and for the second on 12 December 2019.[664] However, EDF Energy claimed that construction only "begins" on the *completion* of the nuclear island's "common raft" (referred to as J-0) which occurred for the first unit in June 2019 and for the second unit in June 2020.[665] By completing a large amount of the work before formally declaring construction began, EDF can claim a shortened construction timetable. Given the construction delays in China, Finland and France, this could be of primary importance for EDF.

663 - Ibidem.

664 - WNISR, "The Oddly Discreet Construction Start of Hinkley Point C", World Nuclear Industry Status Report, 29 December 2018, see https://www.worldnuclearreport.org/The-Oddly-Discreet-Construction-Start-of-Hinkley-Point-C.html, accessed 21 May 2020.

665 - EDF, "Hinkley Point C nuclear power project achieves latest major milestone on schedule", 1 June 2020, see https://www.edfenergy.com/media-centre/news-releases/hinkley-point-c-nuclear-power-project-achieves-latest-major-milestone, accessed 1 June 2020.

The critical points of the Hinkley 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 £89.5–92.5/MWh, in 2012 values (US$$_{2020}$110–115/MWh), with annual increases linked to the Retail Price Index. In early 2020, EDF broke down the £92.50/MWh (US115_{2020}$) strike price saying that £19.5 (US$$_{2020}$24.1) would go toward operating and maintenance costs, and only £11 (US$$_{2020}$13.6) to standard construction costs, excluding financing. The remaining £62 (US$$_{2020}$76.8) covers risk, with £26 (US$$_{2020}$32.2) for financing costs "for typical regulated asset without construction risk" and £36 (US$$_{2020}$44.6) to cover first-of-a-kind construction risk.[666] The validity of and rationale for releasing these figures remain unclear. On the one hand, it could be designed to say that the cost of construction has been inflated in the U.K. due to the particular conditions in the U.K. leading to an extremely high cost of risk. However, on the other hand, it does highlight that building reactors is financially extremely risky.

"The deal for HPC has locked consumers into a risky and expensive project with uncertain strategic and economic benefits"

The cost of this support scheme has rocketed and the U.K. National Audit Office (NAO) suggested that the additional 'top-up' payments—the difference between the wholesale price (as of the beginning of 2020 at £36/MWh) and the agreed fixed price (or Strike Price), required through the CfD—have increased from £6.1 billion (US$$_{2013}$9.9 billion) in October 2013 to £29.7 billion (US$$_{2016}$41.2 billion in March 2016. This was due to falling wholesale electricity prices. This is the discounted[667] estimate, and the undiscounted estimate would be closer to £50 billion (US$$_{2020}$62 billion) The NAO also stated that "the [Government] Department's deal for HPC has locked consumers into a risky and expensive project with uncertain strategic and economic benefits."[668]

There was an expectation that construction would be primarily funded by debt (borrowing) backed by U.K. sovereign loan guarantees, expected to be about £17 billion (US$26.9 billion). EDF announced in November 2015 its intention to sell non-core assets worth up to €10 billion (US$11.4 billion), including a stake in Lake Acquisitions, to help finance HPC and other capital-intensive projects.[669]

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 and the other investors 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 per cent.[670]

666 - Phil Chaffee, "Industry Pushes for Government Action", *NIW*, 6 March 2020.

667 - Discounting reduces the nominal value of costs and estimates the further in the future they occur.

668 - NAO, "Hinkley Point C", Report by the Comptroller and Auditor General, Department for Business, Energy & Industrial Strategy, June 2017, p.12, see https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-C.pdf, accessed 21 May 2020.

669 - 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.

670 - Steve Thomas and Alison Downes, "Financing the Hinkley Point C", Commissioned by the Therberton & Eastbridge Action Group on Sizewell, January 2020, see https://www.nuclearconsult.com/wp/wp-content/uploads/2020/01/HPC-finance-Steve-Thomas.pdf, accessed 21 May 2020.

The administration of Prime Minister Theresa May finally approved the HPC project in September 2016, with the Government retaining a 'special share', that would give it a veto right over changes to ownership, if national security concerns arose.[671] The U.S. Government continues to have security concerns and in October 2018 Assistant Secretary of State, Christopher Ashley Ford, even 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.[672]

The construction of the plant has also been affected by the COVID-19 pandemic, but construction was not stopped, despite concerns about the ability of large construction projects to adequately social distance. During April 2020, the number of construction workers was reduced to about 2,500, fewer than half of what it was at the beginning of the year.[673] The economic consequences of the pandemic also led investors to lose confidence and in March 2020, within two weeks, EDF Group lost half of its stock-market value, when shares plunged to historically low levels (see France Focus).

Other U.K. New-Build Projects

Sizewell C

EDF and CGN are also preparing to launch the development of the follow-on to Hinkley Point C (HPC), the Sizewell C project. Chinese investment would be limited to 20 percent, leaving EDF with 80 percent. However, these relative values could change in the event of the Government agreeing to a new financing model. Given the 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 March 2020; but the pandemic and the Government's control measures led to a delay.[674] On 24 June 2020, the Planning Inspectorate, accepted the application and consequently the next stage of the planning processes could begin.[675] The final decision on whether to grant a development consent order to build Sizewell-C will be taken by the Government.[676]

EDF are hoping that they 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

671 - 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 21 May 2020.

672 - 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.

673 - EDF Energy, "Coronavirus update from Hinkley Point C - May 5", EDF, 5 May 2020, see https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/news-views/coronavirus-update-from-hinkley-point-c-5-may, accessed 21 May 2020.

674 - EDF Energy, "Sizewell C submits planning application", 27 May 2020, see https://www.edfenergy.com/media-centre/news-releases/sizewell-c-dco, accessed 6 June 2020.

675 - The Planning Inspectorate, "Application by NNB Nuclear Generation (SZC) Limited for an Order Granting Development Consent for The Sizewell C Project", Ministry of Housing, Communities and Local Government, 24 June 2020, see https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010012/EN010012-002268-A05%20Notification%20of%20decision%20to%20accept%20application_.pdf, accessed 26 June 2020.

676 - *ITV*, "Sizewell C delay to give locked down communities more time to have their say", 26 March 2020, see https://www.itv.com/news/anglia/2020-03-26/sizewell-c-delay-to-give-locked-down-communities-more-time-to-have-their-say/, accessed 21 May 2020.

construction start date of Sizewell C in 2022, this seems unlikely. EDF is optimistic that it can reduce construction costs, with their current estimate is put at £18 billion (US$22 billion).[677] However, they are also hoping that the financing costs of Sizewell-C can be reduced by shifting from the CfD mechanism to the Regulated Asset Base model. EDF have 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)[678] 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.[679] 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, and therefore, it was expected that Sizewell C would be £18 billion (US$22.3 billion).[680] However, without the development of a new financing model and confidence that the problems that have plagued the construction of EPRs around the world have been solved, it is unlikely, especially in the current economic climate, that Sizewell C will proceed.

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.[681] In January 2017, the U.K. Government requested that the regulator begin the Generic Design Assessment (GDA) of the HPR-1000 reactor.[682] By November 2018 the Office for Nuclear Regulation (ONR) and the Environment Agency had completed a high level scrutiny of the design,[683] and by February 2020 the ONR had completed Step 3 of the GDA, with the final Step expected to be completed by the end of 2021, with a closure stage potentially taking another year.[684] The key moment in the GDA, when specific issues are identified, is Step 4. 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 the likelihood of a global recession.

Moorside

In June 2014, NuGen finalized a new ownership structure with Toshiba-Westinghouse (60 percent) and Engie – then GDF Suez – (40 percent), as Iberdrola sold its shares to

677 - *NEI*, "Plans for Sizewell C submitted to UK Planning Inspectorate", 28 May 2020, see https://www.neimagazine.com/news/newsplans-for-sizewell-c-submitted-to-uk-planning-inspectorate-7943163, accessed 30 May 2020.

678 - Phil Chaffee, "Industry Pushes for Government Action", *NIW*, 2020, op.cit.

679 - Roger Murray, "Hinkley Point Cost Overrun- Bad News for Sizewell C?", *NIW*, 27 September 2019.

680 - *Financial Times*, "Cost of new Sizewell C nuclear plant put at £20bn", 26 June 2020, see https://www.ft.com/content/77c209f7-6d18-4609-ac3c-77d1b5b82b34, accessed 26 June 2020.

681 - 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 21 May 2020.

682 - 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 21 May 2020.

683 - ONR, "UK HPR1000 completes GDA Step 2", 15 November 2018, see http://news.onr.org.uk/2018/11/uk-hpr1000-completes-gda-step-2/, accessed 21 May 2020.

684 - ONR, "Generic Design Assessment (GDA) of new reactors—Timeline", Undated, see http://www.onr.org.uk/new-reactors/timeline.htm, accessed 21 May 2020.

Toshiba-Westinghouse. The group planned to build three Toshiba-Westinghouse-designed AP1000 reactors at the Moorside site, with units proposed to begin operating in 2024.[685] However, Westinghouse, after its financial collapse, filed for Chapter 11 bankruptcy protection in the U.S. in March 2017. This had a disastrous impact on the parent company Toshiba, when the extent of Westinghouse's problems came to light.[686] The perilous state of the project also led to Engie selling its remaining 40 percent to Toshiba-Westinghouse for US$138 million, who were contractually obliged to buy at pre-determined price. In late April 2017, Toshiba started mothballing the project.[687] Amongst all this economic chaos, the U.K. Office of Nuclear Regulation had approved the AP1000 reactor design on 30 March 2017.[688]

Toshiba was initially in talks with both Korea's KEPCO, a nationally owned utility and reactor vendor, and CGN of China, as potential buyers of NuGen. In October 2017, the CEO of NuGen said that they were expecting to find a buyer by early 2018,[689] but KEPCO put off a decision until the autumn of 2018 and said they would only proceed if "a preliminary analysis concludes the project serves the national interests."[690] However, in November 2018, Toshiba announced that it was winding down NuGen, without finding a buyer. This might open up the opportunities for others to buy the Moorside site and build their own reactors—although this has not yet occurred. In the meantime, the Moorside site has reverted to the U.K.'s Nuclear Decommissioning Authority.

Wylfa and Oldbury

The other company that was involved in the proposed nuclear new-build is Horizon Nuclear Power, which was bought by the Japanese company Hitachi-GE from German utilities E.ON and Rheinisch-Westfälisches Elektrizitätswerk (RWE) for an estimated price of £700 million (US$1.2 billion) in 2012. The company submitted its Advanced Boiling Water Reactor (ABWR) design for technical review, whilst at the time making it clear that its continuation in the project would depend on the outcome of the negotiations with the Government.[691]

Hitachi was looking for partners in their project, hoping to reduce their stake to 50 percent and, if no other investors could be found, the company would have to withdraw. An internal review had found that the construction cost was likely to reach US$27.5 billion, considered too big a risk for the company on its own. In June 2018, the U.K. Government formally announced that it was considering taking an equity stake in the Wylfa project. However, Energy Secretary Greg Clark while "reaffirming the government's commitment to nuclear", also stated a strike

685 - David Dalton, "Toshiba Finalises Controlling Stake In UK Nuclear Company NuGen", *NucNet*, 30 June 2014, see https://www.nucnet.org/all-the-news/2014/06/30/toshiba-finalises-controlling-stake-in-uk-nuclear-company-nugen, accessed 23 May 2020.

686 - Kana Inagaki, "Westinghouse files for Chapter 11 bankruptcy protection", *Financial Times*, 29 March 2017, see https://www.ft.com/content/ba9d8e42-de63-320e-b29c-70dcf19e1f28, accessed 23 May 2020.

687 - John Collingridge, "Toshiba mothballs Cumbrian nuclear power project", *The Sunday Times*, 30 April 2017.

688 - ONR, "Design acceptance for the AP1000 reactor", 30 March 2017, see http://news.onr.org.uk/2017/03/design-acceptance-for-the-ap1000-reactor/, accessed 23 May 2020.

689 - *NIW*, "United Kingdom", 6 October 2017.

690 - Phil Chaffee, "With Eyes on Saudi Arabia, Kepco Treads Water in the UK", *NIW*, 4 May 2018.

691 - Ambrose Evans-Pritchard, "Hitachi reluctant about UK nuclear reactor plan", *The Telegraph*, 14 April 2013, see https://www.telegraph.co.uk/finance/newsbysector/energy/9993564/Hitachi-reluctant-about-UK-nuclear-reactor-plan.html, accessed 23 May 2020.

price above £75/MWh (US$96.5/MWh) could not be justified for new nuclear.[692] In January 2019, Hitachi announced that it was suspending the project and that this decision was taken "from the standpoint of economic rationality"; in doing so the company accepted a ¥300 billion (US$$_{2019}$2.75 billion) impairment. Hitachi pointed to "significant changes in the power market environment," including the rising competitiveness of renewable energies.[693]

Against all odds, the project is officially still going through the U.K.'s planning processes and the Secretary of State has set a new deadline for the decision on the development consent order for this application to the 30 September 2020.[694]

A New Funding Model for Nuclear New-build?

In July 2019, the Government announced a consultation for the introduction of a new funding model to facilitate the construction of new nuclear via a Regulated Asset Base (RAB) with a simple idea: "In the case of a nuclear RAB, suppliers would be charged as users of the electricity system and would be able to pass these costs onto their consumers who also use the electricity system".[695] If approved by the Government, the project developer could charge consumers upfront for the construction, which would be broken down into different phases during the build process. EDF have claimed that all households would have to pay only £6 (US$7.5) per year additionally for them to build the proposed reactors at Sizewell C.[696] In the U.S., this model has led to at least nine tariff increases for consumers for the construction of the two V.C. Summer reactors in South Carolina, started in 2012 and abandoned in 2017 after the expenditure of over US$10 billion (see previous editions of the WNISR). The financing scheme had been abandoned by most of the U.S. states in the 1970s and led to the cancellation of more reactor orders than were eventually carried through.

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 Hinkley Point C (HPC) to around 5.5–6 percent.[697] However, as a paper by the National Infrastructure Commission concludes:

692 - Greg Clark, "Statement on suspension of work on the Wylfa Newydd nuclear project", Business and Energy Secretary, Oral Statement to Parliament, BEIS, 17 January 2019, see https://www.gov.uk/government/speeches/statement-on-suspension-of-work-on-thewylfa-newyddnuclear-project, accessed 4 August 2020.

693 - Dennis Engbarth, "Hitachi Cites 'Economic Rationality' for Wylfa Decision", *NIW*, 1 January 2019.

694 - National Infrastructure Planning, "Wylfa Newydd Nuclear Power Station", 1 April 2020, see https://infrastructure.planninginspectorate.gov.uk/projects/wales/wylfa-newydd-nuclear-power-station/, accessed 30 May 2020.

695 - BEIS, "RAB Model for Nuclear—Consultation on a RAB model for new nuclear projects", Department for Business, Energy & Industrial Strategy, U.K. Government, July 2019, see https://www.gov.uk/government/consultations/regulated-asset-base-rab-model-for-nuclear, accessed 23 May 2020.

696 - 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.

697 - 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.

> …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.[698]

For nuclear, the segmented RAB might include:

> …initial costs of preparing to get started; the costs of laying the foundations; the installation of the reactor; and commissioning - and at each stage, with the costs agreed in advance, there would be scrutiny by the regulator and then, subject to this efficiency test, these costs would then go into the RAB and be recovered from the use of systems charges.[699]

However, even following the consultation, it is far from clear, if the RAB does proceed, and if yes, how it will be structured.

A key selling point for the Government is that funding does not have to come from the Treasury—and therefore remains off the Government's balance sheet—and that it removes the need for or at least reduces the cost level of the Contract for Difference, which highlights the high cost of nuclear compared to all other power generating sources. However, the price to consumers will most likely still go up (presumably on an annual basis) so that investors earn their guaranteed rate of return.

"the price to consumers will most likely still go up so that investors earn their guaranteed rate of return"

Using RAB financing would bring with it particular characteristics compared to using this model in other sectors, which include: the capital required to construct a new nuclear plant is significant, which could lead to different outcomes in terms of the availability of project financing; nuclear plants come with complex construction requirements which creates material uncertainty in cost forecasts that cannot be resolved until construction is started and the limitations in the expertise available to assess the efficiency of forecast and outturn expenditure due to a lack of comparable data and the unique characteristics of each new nuclear plant built.[700]

Furthermore, this model is seen as transferring the financing risks away from the project promoter, as the *Financial Times* pointed out:

> What RAB financing does is transfer project risks to customers, who are least well placed to bear them," said [the late] Martin Blaiklock, an infrastructure expert who likened the technique to "being forced to pay for a meal at a restaurant before the restaurant has even been built, let alone served any food.[701]

698 - National Infrastructure Commission, "Estimating comparable costs of a nuclear regulated asset base versus a contract for difference financing model", October 2019, see https://www.nic.org.uk/wp-content/uploads/NIC_RAB_Paper_October_2019-3rd-Layout-003.pdf, accessed 30 May 2020.

699 - Dieter Helm, "The Nuclear RAB Model", 12 June 2018, see http://www.dieterhelm.co.uk/energy/energy/the-nuclear-rab-model/, accessed 23 May 2020.

700 - National Infrastructure Commission, "Estimating Comparable Costs of a Nuclear Regulated Asset Base versus a Contract for Difference Financing Model", October 2019, op.cit.

701 - Jonathan Ford, "EDF seeks to charge customers upfront for UK nuclear plants", *Financial Times*, 2018, op.cit.

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 the risk of highly material increases in the volume of capital that consumers will need to finance.[702]

The U.K. Government asked for comments on the proposal until October 2019, but have not made any statements since, much to the industry's frustration. In March 2020 the Nuclear Industry Association wrote to the Government urging them to respond to the RAB consultation and develop a "'a robust financing model" that "is in place before the end of 2020".[703]

Over the last few years, the Government's agenda has been dominated by Brexit and now the COVID pandemic, squeezing out discussions and the attention of ministers and civil servants around energy and nuclear power. While it is possible that space in the political agenda may be found to conclude internal discussions around the RAB, given the economics of the country and likely recession, the Government will undoubtedly be extremely wary about new measures that will visibly add costs to consumers' bills.

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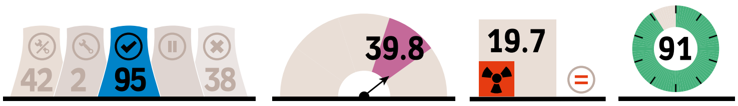


Overview

With 95 commercial reactors operating as of 1 July 2020,[704] the U.S. possesses the largest nuclear fleet in the world. Two reactors were closed in the year since WNISR2019. The Three Mile Island (TMI) Unit 1 was withdrawn from the grid on 20 September 2019.[705] The 45-year old 819-MW PWR, located near Middletown in Pennsylvania, was first connected to the grid on 19 June 1974. The closure brought to an end nuclear generation at the site where Unit 2 in 1979 suffered a partial core-melt accident. On 20 April 2020, the Indian Point-2 reactor was closed.[706] Construction has 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. As in previous years, evidence has continued to emerge of the enormous scale of the problems with the Vogtle project. During the past year, there have been multiple disclosures of failure of installed components, further

702 - Citizens Advice, "Response to BEIS consultation on whether it should move to a Regulated Asset Base (RAB) model to finance new nuclear power stations", 11 October 2019, see http://www.citizensadvice.org.uk/about-us/policy/policy-research-topics/energy-policy-research-and-consultation-responses/energy-consultation-responses/response-to-beis-consultation-on-whether-it-should-move-to-a-regulated-asset-base-rab-model-to-finance-new-nuclear-power-stations/, accessed 23 May 2020.

703 - Phil Chaffee, "Industry Pushes for Government Action", *NIW*, 2020, op. cit.

704 - Duane Arnold-1 was closed on 10 August 2020, following significant storm damage, four months earlier than scheduled. That leaves 94 reactors operating in the U.S. as of the end of August 2020; see WNISR, "Storm Damage Prompts Early Closure of Duane Arnold Nuclear Reactor in the U.S.", 26 August 2020, see https://www.worldnuclearreport.org/Storm-Damage-Prompts-Early-Closure-of-Duane-Arnold-Nuclear-Reactor-in-the-U-S.html, accessed 27 August 2020.

705 - WNISR, "Three Mile Island-1 Closed at Age 45", 22 September 2019, see https://www.worldnuclearreport.org/Three-Mile-Island-1-Closed-at-Age-45.html, accessed 1 July 2020.

706 - WNISR, "Closure of 47-Year-Old Indian Point Reactor Near New York City", 30 April 2020, see https://www.worldnuclearreport.org/Closure-of-47-Year-Old-Indian-Point-Reactor-Near-New-York-City.html, accessed 1 July 2020.

cost increases and almost certain further delays in startup.[707] The owners continue to hold to their latest estimated operational dates of November 2021 and November 2022, five years later than originally planned.

In June 2020, it was confirmed that the former CEO of SCANA, the parent company of South Carolina Electric & Gas (SCG&E) and owner of the abandoned V.C. Summer plant, will plead guilty to defrauding investors and utility customers. Documents released during the past year allege that the CEO and other officials conducted, "a years-long cover-up to hide huge losses in then-ongoing construction at the V.C. Summer nuclear plant."708 This follows the July 2017 to terminate construction of the twin V.C. Summer AP-1000 reactor project in South Carolina.[709] The guilty plea follows FBI criminal investigations into the failed nuclear project, which cost South Carolina power customers billions of dollars. Investigations are on-going and federal officials in June stated that they "anticipate filing additional criminal charges against other members of the conspiracy."[710]

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 2020, 13 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, FitzPatrick and Ginna in New York; Clinton and Quad Cities in Illinois; Salem and Hope Creek in New Jersey; Millstone in Connecticut; Davis Besse and Perry in Ohio. While it is inevitable that the size of the U.S. nuclear fleet will continue to decline for the foreseeable future, the decline is likely to be slowed by directly subsidizing economically threatened operating plants.

The U.S. reactor fleet provided 809.4 TWh in 2019, compared to 808.03 TWh in 2018, a new record. The fleet's mean load factor was 90.6 percent, amongst the Top Ten in the world while by far operating the largest number of reactors (nonsensical to compare e.g. to Slovenia with one unit). Nuclear plants provided 19.7 percent of electricity in 2019, compared to 19.3 percent of U.S. electricity in 2018, and about 3 percentage points below the highest nuclear share of 22.5 percent, reached in 1995.

With only one new reactor started up in the past 20 years, the U.S. fleet continues to age, with a mid-2020 average of 39.8 years, amongst the oldest in the world: 46 units have operated for 41 and more years and all but six for 31 and more years (see Figure 43).

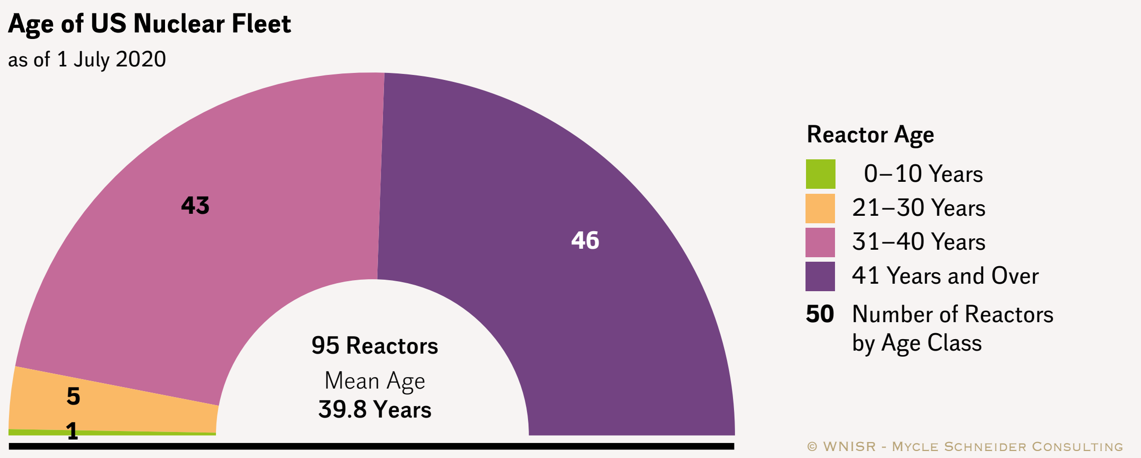
707 - Matt Kempner, "Georgia Vogtle nuclear report: more delays, $1B in extra costs, flaws", *The Atlanta Journal-Constitution*, 9 June 2020, see https://www.ajc.com/news/local/georgia-vogtle-nuclear-report-more-delays-extra-costs-flaws/mBxlgXiDcfoSIaTFrocZXL/, accessed 1 July 2020.

708 - *The State*, "SCANA conspirators helped Byrne spin lies about nuclear project, document alleges", 9 June 2020, see https://www.thestate.com/news/local/crime/article243395241.html, accessed 5 July 2020.

709 - SCANA, "South Carolina Electric & Gas Company To Cease Construction And Will File Plan Of Abandonment Of The New Nuclear Project", CISION PR Newswire, 31 July 2017, see https://www.prnewswire.com/news-releases/south-carolina-electric--gas-company-to-cease-construction-and-will-file-plan-of-abandonment-of-the-new-nuclear-project-300496644.html, accessed 10 May 2019.

710 - *PowerMag*, "Senior Exec Will Plead Guilty to Fraud in Abandoned Nuclear Project", 8 June 2020, see https://www.powermag.com/senior-exec-will-plead-guilty-to-fraud-in-abandoned-nuclear-project/, accessed 5 July 2020.

Figure 43 · Age Distribution of the U.S. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2020

As of 1 July 2020, 87 of the 95 operating U.S. units had already received a license extension. In the past year, the Nuclear Regulatory Commission (NRC) did not issue any additional 20-year license renewals. 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. However, 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".[711] As of 1 July 2020, a total of six reactors have applied for subsequent license renewal, four of which have been approved during the past 12 months.

The NRC on 4 December 2019 issued its first ever subsequent license renewal for Turkey Point-3 and -4. The license grants Florida Light and Power (FL&P), permission to operate the reactors for a total of 80 years.[712] The reactors are located 32 kilometers (20 miles) miles south of Miami and their previous 20 year license extensions, which were granted in 2002, had allowed them to operate until 2032 and 2033. FL&P applied for an additional 20 years of operation in May 2018.[713]

711 - Office of Nuclear Reactor Regulation, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report", NRC, Final Report, NUREG-2191, Vol. 2, July 2017, see https://www.nrc.gov/docs/ML1718/ML17187A204.pdf, accessed 10 June 2020.

712 - NRC, "ISSUANCE Of Subsequent Renewed Facility Operating License Nos. DPR-31 And DPR-41 For Turkey Point Nuclear Generating Unit Nos. 3 And 4 (EPID L-2018-RNW-0002)", 4 December 2019, see https://www.nrc.gov/docs/ML1930/ML19305C879.pdf; and Utility Dive, "FPL's Turkey Point first US nuclear plant to get license out to 80 years", 4 December 2020, see https://www.utilitydive.com/news/fpls-turkey-point-first-us-nuclear-plant-to-get-license-out-to-80-years/568593/, both accessed 2 July 2020.

713 - NRC, "Turkey Point Nuclear Plant, Units 3 & 4 – Subsequent License Renewal Application", see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/turkey-point-subsequent.html, accessed 11 May 2019.

On 5 March 2020, the NRC granted subsequent license renewal for the Peach Bottom Unit 2 and Unit 3 owned by the Exelon Generation Company, LLC (Exelon).[714] Prior to this decision, Peach Bottom Unit 2 had an operating license until 8 August 2033, while the license for Peach Bottom Unit 3 was to run until 2 July 2034.[715] Exelon Generation Company, LLC (Exelon), applied to the NRC on 10 July 2018 for subsequent license renewal for the reactors.[716] Peach Bottom-2 and -3 were both connected to the grid in 1974 and are General Electric MK1 Boiling Water Reactors (BWRs). With the additional extension of 20 years, the reactors are licensed to operate until 8 August 2053 and 2 July 2054 respectively.

The subsequent license renewals for Peach Bottom-2 and-3 were contested by the organization Beyond Nuclear.[717] In evidence, seeking a review by the Atomic Safety Licensing Board (ASLB), expert witness David Lochbaum contends that Exelon in its application to the NRC had failed to provide evidence of adequate aging management programs and on how operating experience will be applied during the 60–80 year period of operation of Peach Bottom-2 and -3. Lochbaum added: "Abundant evidence also speaks to gaps, deficiencies, and uncertainties in present understanding of aging degradation mechanisms."[718] The ASLB on 20 June 2019 denied the request for a review. As of 1 July 2020, the issue remains under appeal to NRC Commissioners.[719] A new filing to the NRC related to non-compliance with the National Environmental Protection Act (NEPA) and NRC regulations 10 CFR § 51.71 was filed in September 2019.[720]

714 - NRC, "Exelon Generation Company, Llc PSEG Nuclear, Llc Docket No. 50-278 Peach Bottom Atomic Power Station, Unit 3 Subsequent Renewed Facility Operating License Subsequent Renewed License No. DPR-56, 5 March 2020, see http://static1.1.sqspcdn.com/static/f/356082/28268685/1583938196653/pch_slr_03052020_approval_ML20024G426.pdf?token=thU59yfOgtDRthueNS6NLUzJ8NY%3D; also NRC, "Peach Bottom Atomic Power Station, Units 2 & 3 – Subsequent License Renewal Application", see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/peach-bottom-subsequent.html; and Beyond Nuclear, "NRC Greenlights Peach Bottom 80-year license extension despite significant safety questions", 12 March 2020, see http://www.beyondnuclear.org/relicensing/; all accessed 2 July 2020.

715 - NRC, "Second Renewal Generic Environmental Impact Statement for License Renewal of Nuclear Plants Supplement 10, Second Renewal Regarding Subsequent License Renewal for Peach Bottom Atomic Power Station Units 2 and 3 Final Report", NUREG-1437 Supplement 10, Office of Nuclear Reactor Regulation, January 2020, see https://www.nrc.gov/docs/ML2002/ML20023A937.pdf, accessed 2 July 2020.

716 - NRC, "Subsequent License Renewal Application: Peach Bottom Atomic Power Station Units 2 and 3— The Second License Renewal Application", Facility Operating License Nos. DPR-44 and DPR-56, 10 July 2018, see https://www.nrc.gov/docs/ML1819/ML18193A773.pdf, accessed 10 May 2019.

717 - NRC, "U.S.NRC Before The Atomic Safety And Licensing Board—In the Matter of Exelon Generation Company, LLC Peach Bottom Atomic Power Station, Units 2 & 3—Beyond Nuclear, Inc.'s Amended Hearing Request And Petition To Intervene", Docket Nos. 50-277/278 SLR, 1 May 2019, see https://www.nrc.gov/docs/ML1912/ML19121A453.pdf; and Lindsay C. VanAsdalan, "Activists challenge license extension for Peach Bottom nuclear plant", York Dispatch, 6 March 2019, see https://eu.yorkdispatch.com/story/news/2019/03/05/activists-challenge-license-extension-peach-bottom-nuclear-plant/3060252002/, both accessed 12 July 2019.

718 - David A. Lochbaum, "Proposed Subsequent License Renewal of Peach Bottom Units 2 and 3: Exelon's Aging Management Programs Fail to Provide Adequate Measures for Consideration of Operating Experience Throughout the Period of Extended Operation", Report prepared for Beyond Nuclear, 16 November 2018; attached to "Declaration of David A. Lochbaum—In the Matter of Exelon Generation Co., L.L.C., Peach Bottom Atomic Power Station, Units 2 & 3", Docket Nos. 50-277/278 SLR, U.S.NRC before the Secretary, 16 November 2018, see http://static1.1.sqspcdn.com/static/f/356082/28029077/1542673242727/PB-SLR_11192018_Attachments+to+Hearing+Request.pdf?token=6dfkmNSlZgmM33rZ%2Fx%2FV4Bp3%2FWk%3D, accessed 12 July 2019.

719 - NRC, "Beyond Nuclear's Brief On Appeal Of LBP-19-05", United States Of America Nuclear Regulatory Commission Before The Commission In the Matter of Exelon Generation Company, LLC) Docket Nos. 50-277/278 SLR Peach Bottom Atomic Power Station, Units 2 & 3, 15 July 2019, see https://www.nrc.gov/docs/ML1919/ML19196A372.pdf, accessed 5 July 2020.

720 - NRC, "Beyond Nuclear, Inc.'s Motion For Leave To File New Contention Based On Draft Supplement 10 To Generic Environmental Impact Statement For Subsequent License Renewal Of Peach Bottom Operating License", United States Of America Nuclear Regulatory Commission Before The Atomic Safety And Licensing Board And The Commission, In the Matter of Exelon Generation Company, LLC Docket Nos. 50-277/278 SLR Peach Bottom Atomic Power Station, 3 September 2019 Units 2 & 3, 3 September 2019, see https://www.nrc.gov/docs/ML1924/ML19246C301.pdf, accessed 5 July 2020.

Currently, the NRC is reviewing the October 2018 subsequent license-renewal application for Surry-1 and -2 in the state of Virginia, owned by Dominion Energy.[721] The NRC has completed its safety[722] and environmental assessment review[723], and while a decision to grant a license was scheduled for June 2020, as of 1 July 2020 the decision had been delayed while Dominion prepared to submit revised documentation related to compliance with the Coastal Zone Management Act.[724]

While not guaranteeing reactors continued operation, multiple applications are expected over the coming years for subsequent license renewals. Applications are scheduled for North Anna-1 and -2 before December 2020, while Duke Energy Corporation has said it plans to seek license extensions for all 11 of its reactors.[725]

Reactor Closures

Three Mile Island (TMI) Unit 1 was closed on 20 September 2019.[726] The 45-year old 819 MW PWR, owned by Exelon Corporation and located near Middletown in Pennsylvania, was connected to the grid on 19 June 1974. The closure brought to an end nuclear generation at the site where on 28 March 1979 TMI Unit 2 suffered a partial core-melt accident.[727]

"Today we celebrate the proud legacy of TMI Unit 1 and the thousands of employees who shared our commitment to safety, operational excellence and environmental stewardship for nearly five decades," Bryan Hanson, Exelon's senior vice president and chief nuclear officer stated.[728] Although in 2009 the reactor had been granted an NRC 20-year license extension to operate until 2034, Exelon announced on 8 May 2019 that TMI-1 would permanently close by 30 September 2019.[729] In August 2015, TMI-1 did not clear the Pennsylvania New Jersey Maryland Interconnection LLC (PJM) electricity-capacity auction for the 2018-2019 planning year,[730] and in 2017 Exelon had warned that failure to approve subsidies by the Pennsylvania

721 - Virginia Electric and Power Company, "Surry Power Station Units 1 and 2 Application for Subsequent License Renewal Technical and Administrative Information", Dominion Energy Virginia or Dominion, October 2018, see https://www.nrc.gov/docs/ML1829/ML18291A828.pdf, accessed 2 July 2020.

722 - NRC, "Surry Power Station Subsequent License Renewal - Issuance of the Final Safety Evaluation", Accession Number: ML20052F520, 9 March 2020, see https://www.nrc.gov/docs/ML2005/ML20052F520.html, accessed 2 July 2020.

723 - NRC, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants Supplement 6, Second Renewal Regarding Subsequent License Renewal for Surry Power Station Units 1 and 2 Final Report", NUREG-1437 Supplement 6 Second Renewal, Office of Nuclear Material Safety and Safeguards, April 2020, see https://www.nrc.gov/docs/ML2007/ML20071D538.pdf, accessed 2 July 2020.

724 - NRC, "Surry, Units 1 and 2 – Subsequent License Renewal Application", as of 1 July 2020, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/surry-subsequent.html#statement, accessed 2 July 2020.

725 - 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.

726 - Exelon Corp, "Three Mile Island Generating Station Unit 1 Retires from Service After 45 Years", 20 September 2019, see https://www.exeloncorp.com/newsroom/three-mile-island-generating-station-unit-1-retires, accessed 2 July 2020.

727 - B. Drummond Ayres Jr., "Three Mile Island: Notes From a Nightmare", *New York Times* 16 April 1979, see https://www.nytimes.com/1979/04/16/archives/three-mile-island-notes-from-a-nightmare-three-mile-island-a.html, accessed 3 July 2020.

728 - Ibidem.

729 - Exelon Corp, "Three Mile Island Unit 1 To Shut Down By September 30, 2019", 8 May 2019, see https://www.exeloncorp.com/newsroom/Pages/Three-Mile-Island-Unit-1-To-Shut-Down-By-September-30,-2019.aspx, accessed 3 July 2020.

730 - *PowerMag*, "Two Exelon Nuclear Plants Fail to Clear PJM Auction", 25 May 2019, see https://www.powermag.com/two-exelon-nuclear-plants-fail-to-clear-pjm-auction/, accessed 3 July 2020.

legislature before 1 June 2019 would lead to the reactor's closure.[731] As of closure date, no such legislation had been passed.

Forty years ago, TMI-2 suffered the most serious accident in U.S. commercial nuclear power plant operating history when its core partially melted on 28 March 1979.[732] In closing down TMI-1, Exelon stressed that it had never owned TMI-2 that suffered the accident.[733] The official President's Commission report on the causes of the accident concluded that a combination of personnel error, design deficiencies, and component failures was responsible.[734] TMI-1 was shut down following the accident but permitted to restart in 1985 against objections from the local community, non-governmental organizations and a Commissioner of the NRC.[735] The NRC issued 20-year life extension approval for TMI Unit 1 in August 2009, granting the reactor operation until 2034.[736]

Indian Point-2 closed on 30 April 2020.[737] Located on the Hudson River, 48 km from Manhattan, New York, the reactor was taken off the grid under the terms of an unusual 8 January 2017 agreement between the nuclear plant owner Entergy, non-governmental organization Riverkeeper and the state of New York.[738] Entergy invested over US$1 billion in the two remaining 1,000 MW Units 2 and 3 in recent years.[739] In April 2007 Entergy filed with the NRC a 20-year license renewal application for both Indian Point operating units beyond the original expiration dates of 2013 and 2015.[740] These subsequently became subject to sustained opposition from citizens groups.[741] As part of the 2017 agreement, Entergy amended its application to the NRC seeking a shorter renewal term. The NRC's Atomic Safety and Licensing Board issued an Order on 13 March 2017, dismissing remaining contentions and closing the adjudicatory hearing on the renewal. The renewed NRC licenses enabled Entergy to operate the reactors through 30 April 2024 for Unit 2 and 30 April 2025 for Unit 3. Unit 1, a smaller 250-MW reactor, was closed in 1974 just 12 years after it had started up.

731 - *Utility Dive*, "After failing to clear PJM auction, Exelon says Three Mile Island nuke will close in 2019", 30 May 2017, see https://www.utilitydive.com/news/after-failing-to-clear-pjm-auction-exelon-says-three-mile-island-nuke-will/443794/, accessed 3 July 2020.

732 - NRC, "Backgrounder on the Three Mile Island Accident", as of June 2018, see https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html, accessed 3 July 2020.

733 - *Reuters*, "Exelon to close Three Mile Island nuclear plant in Pennsylvania on Friday", 20 September 2019, see https://www.reuters.com/article/us-usa-nuclear-threemileisland/exelon-to-close-three-mile-island-nuclear-plant-in-pennsylvania-on-friday-idUSKBN1W51FD, accessed 3 July 2020.

734 - President's Commission on the Accident at Three Mile Island, "The Need For Change: The Legacy Of TMI", 30 October 1979, see http://large.stanford.edu/courses/2012/ph241/tran1/docs/188.pdf, accessed 3 July 2020.

735 - TMI Alert, "Commemoration of the 40th Anniversary of the Beginning of the Three Mile Island Unit 2 Accident", March 2019, see http://www.tmia.com/sites/tmia.com/files/media/Press-Packet.pdf, accessed 3 July 2020.

736 - NRC, "Three Mile Island Nuclear Station, Unit 1 - License Renewal Application", as of April 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/three-mile-island.html#appls, accessed 3 July 2020.

737 - Entergy, "Entergy's Indian Point Unit 2 to Shut Down Permanently", 29 April 2020, see https://www.entergynewsroom.com/news/entergy-s-indian-point-unit-2-shut-down-permanently/, accessed 3 July 2020.

738 - Riverkeeper, "Indian Point Closure FAQ", see https://www.riverkeeper.org/campaigns/stop-polluters/indian-point/indian-point-closure-faq/, accessed 3 July 2020.

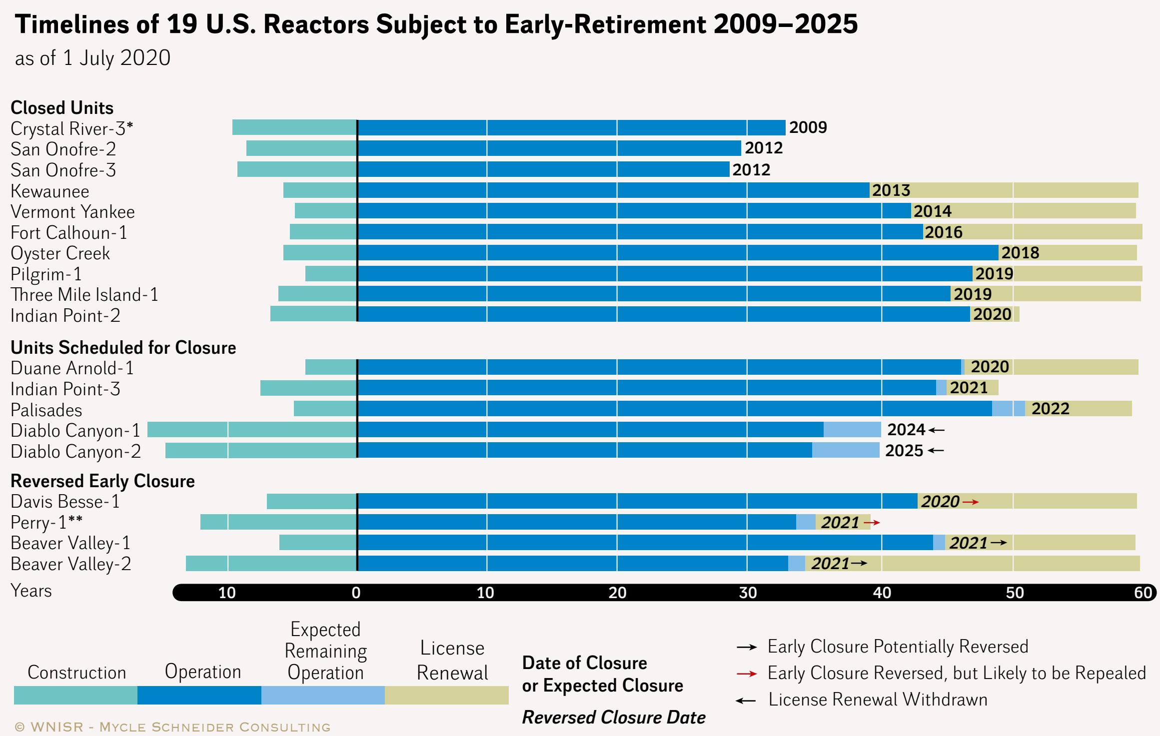
739 - *WNN*, "Entergy agrees to Indian Point closure", 9 January 2017, see https://www.world-nuclear-news.org/Articles/Entergy-agrees-to-Indian-Point-closure, accessed 3 July 2020.

740 - NRC, "NRC Renews Operating Licenses for Indian Point Nuclear Power Plant Units 2 and 3", 17 September 2018, see https://www.nrc.gov/docs/ML1828/ML18283A096.pdf, accessed 3 July 2020.

741 - Vivian Yee and Patrick McGeehan, "Indian Point Nuclear Power Plant Could Close by 2021", *The New York Times*, 6 January 2017, see https://www.nytimes.com/2017/01/06/nyregion/indian-point-nuclear-power-plant-shutdown.html, accessed 3 July 2020.

Connected to the grid on 26 June 1973, Unit 2, along with Unit 3 that followed on 27 April 1976, have long been challenged on two crucial environmental requirements: a coastal zone management certification and a water permit application. While Entergy had declared that it was exempt from needing the coastal zone management certification, New York State disagreed. The two parties continued through 2016 to battle it out in the Court of Appeals.[742]

Figure 44 · Timelines of Early Retirement in the United States



Sources: Various, compiled by WNISR, 2020

Notes:

* Crystal River: No production after 2009 (WNISR considers it closed as of this date). Official closure announced in 2013. Renewal application submitted in 2008, withdrawn in 2013. See U.S. NRC, "Crystal River – License Renewal Application", Updated 9 December 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/crystal-river.html, accessed 8 September 2020.

** License Renewal Application cancelled in 2018. See FENOC, "Perry Nuclear Power Plant—Change of Intent to Submit License Renewal Application", First Energy Nuclear Operating Company, 27 November 2018, see https://www.nrc.gov/docs/ML1833/ML18331A155.pdf, accessed 8 September 2020.

According to the 2017 agreement, Indian Point Unit 2 was to shut down no later than 30 April 2020 and Unit 3 no later than 30 April 2021. Entergy has also stated that low natural gas prices and increased operating costs of the reactors were key factors in its decision to close Indian Point.[743] A recent study highlighted that rather than increasing natural gas electricity generation to meet New York state 2025 clean energy targets, there will have to be a build

742 - Chris Dolmetsch and Mark Chediak, "Cuomo Wins Round in Bid to Shut Entergy's Indian Point Plant", *Bloomberg*, 21 November 2016, see https://www.bloomberg.com/news/articles/2016-11-21/entergy-s-new-york-nuke-plant-needs-coastal-review-court-says, accessed 3 July 2020.

743 - Mary Esch, "Curtain lowers on nuke plant a stone's throw from Manhattan", *Associated Press*, 29 April 2020, see https://apnews.com/41b32c474b9aa75bf4261bdac1816e22, accessed 3 July 2020.

out of renewables, storage, and energy efficiency far exceeding the loss in generation from the Indian Point reactors.[744]

Table 9 · 15 Early-Retirements for U.S. Reactors 2009–2025

Reactor	Owner	Decision Date	Closure/Expected Closure Date (last electricity generation)	Age at Closure (in years)	NRC 60-Year License Approval
Oyster Creek	Exelon	8 December 2010	December 2019 brought forward to 17 September 2018	49	Yes
Crystal River-3	Duke Energy	5 February 2013	26 September 2009	32	Application withdrawn
San Onofre-2 & -3	SCE/SDG&E	7 June 2013	January 2012	29 / 28	No application
Kewaunee	Dominion Energy	22 October 2012	7 May 2013	39	Yes
Vermont Yankee	Entergy	28 August 2013	29 December 2014	42	Yes
Pilgrim	Entergy	13 October 2015	31 May 2019	47	Yes
Diablo Canyon-1 & -2	PG&E	21 June 2016	November 2024 & August 2025	40	Suspended
Fort Calhoun	OPPD	26 August 2016	24 October 2016	43	Yes
Palisades	Entergy	8 December 2016/ 28 September 2017	2022	51	Yes
Indian Point-2	Entergy	9 January 2017	30 April 2020	47	Yes
Indian Point-3			30 April 2021	44	
Three Mile Island-1	Exelon	30 May 2017	September 2019	45	Yes
Duane Arnold	NextEra	27 July 2018	30 October 2020	46	Yes

Sources: Various, compiled by WNISR, 2020

Notes:

As anticipated in WNISR2019, early closure decisions for four reactors (Beaver Valley-1 and -2, Davis-Besse and Perry) have been reversed (see section on Securing Subsidies to Prevent Closures), and those reactors have been removed from the table in the WNISR2020 version.

SCE: Southern California Edison; SDG&E: San Diego Gas & Electric; PG&E: Pacific Gas & Electric Company; OPPD: Omaha Public Power District.

744 - PSE, "Evaluating the potential for renewables, storage, and energy efficiency to offset retiring nuclear power generation in New York", April 2020, see https://www.psehealthyenergy.org/wp-content/uploads/2020/04/PSE-Research-Brief_-Indian-Point_4_13_20.pdf, accessed 3 July 2020.

Reactor Construction

"Simply stated, it is to develop an unachievable plan, fail relatively quickly, and repeat the process to develop a new (and still unachievable) plan."

Georgia Public Service Commission Public Interest Advocacy Staff, on Southern Company approach to Vogtle Construction[745]

The Vogtle Debacle

Only two commercial reactors are currently under construction in the U.S. – the AP-1000 reactors Vogtle-3, which officially began in March 2013, and Vogtle-4, which began in November 2013.[746] The reactors are being built in Burke County, near Waynesboro, in the state of 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 gave fuel-loading times as November 2021 for Unit 3 and November 2022 for Unit 4, which compares with an original planned startup date of 2016. However, the operational dates from Southern are at variance with the assessment made by the Georgia Public Services Commission (PSC) staff in its December 2016 quarterly progress report, which indicated a credible completion date of 2023.[747]

While the project during the past year has passed certain construction milestones, as in previous years, evidence continues to emerge that reveals the enormous scale of the Vogtle project failure.

As of March 2020, construction was 81.2 percent complete, with the total project at 85.7 percent. Milestones achieved included: Unit 3 conical roof structure on top of the shield building; Unit 3 main control room declared to be ready to support testing; installed reactor coolant pump variable frequency drive units; set Unit 4 third containment vessel ring; installed Unit 4 passive residual heat exchanger. However, these achievements mask the continuing delays in the project. In expert testimony to the Georgia PSC on 5 June 2020, it was concluded that

> ...in spite of achieving these construction milestones, construction progress on the Project continued to fall behind the production needed to achieve the April 2019 Baseline with a Unit 3 COD (Commercial Operation Date) of May 23, 2021.[748]

It was also pointed out that construction milestones are reported by the contractors as successful when they are started, rather than when they are completed, which means, "that they do not provide an accurate status of the Project."[749]

745 - Georgia Public Service Commission, 5 June 2020, op. cit.

746 - WNISR, "Construction Start on US Vogtle Unit 4", 25 November 2013, see https://www.worldnuclearreport.org/Construction-Start-on-US-Vogtle.html, accessed 28 May 2019.

747 - Kristi E. Schwartz, "Evidence mounts that Vogtle project won't start up in 2020", *E&E News*, 8 February 2017, see https://www.eenews.net/energywire/2017/02/08/stories/1060049693, accessed 28 May 2019.

748 - Georgia Public Service Commission, "Direct Testimony And Exhibits Of Steven D. Roetger William R. Jacobs, Jr., Phd., In The Matter Of Georgia Power Company's Twenty-Second Semi-Annual Vogtle Construction Monitoring Report Docket No. 29849, On Behalf Of The Georgia Public Service Commission Public Interest Advocacy Staff", 5 June 2020.

749 - Ibidem.

In June 2020, in damning expert-witness evidence to the Georgia PSC, it was concluded that the construction schedule will not be met and the budget awarded by the PSC will be exceeded. The evidence was submitted by Donald Grace, Vice President of Engineering for the Vogtle Monitoring Group ("VMG") which is engaged by the Georgia Public Service Commission ("GPSC") Public Interest Advocacy ("PIA") Staff which is tasked with independently evaluating Southern's ability to successfully manage completion of the Vogtle project.[750] The evidence showed for example that the Schedule Performance Indices (SPIs) for weekly installation of Instrumentation and Control (I&C) cable pulling and termination show swings in values that, "are "off the chart" (both figuratively, and actually off the scale of Chart)", with performance that is "erratic and unpredictable".[751] On terms of completing this major task, on current schedule it could take

> 57.5 months (i.e., 5.75 x 10 months) to complete the amount of termination effort that had been planned to be completed during this 10-month period…This leads to the conclusion that the project is having difficulty in establishing, and then working to, an achievable plan.[752]

In any construction of a nuclear plant, the performance of the many tens of thousands of installed components is critical. The testing of components, the so-called Inspection and Test Plan (ITPs) for the Vogtle reactors revealed according to VMG that

> the test failure rate is at an unacceptably high rate of roughly 80%…In the professional opinion of VMG it is much greater (by at least a factor of 4) of what one should expect…(and in conclusion) All the above greatly increases the complexity of planning work and providing meaningful reports of progress vs plan (as evidenced by there being more than 60,000 remaining activities within the IPS - Integrated Project Schedules).[753]

Upon discovery that 80 percent of tested components failed, the PSC staff expressed shock, given that

> While some problems are expected during this phase but a failure rate of 80% indicates that construction, quality control and ITP in their normal daily functions are not doing an adequate job to verify that the components are ready for testing.[754]

VMG warned that

> The component test failure rate is indeed a serious issue; however, it is too early to tell whether the extent of the failures are the result of ITP's performance (e.g., not properly

750 - Georgia PSC Public Interest Advocacy Staff, "Direct Testimony Of Donald N. Grace P.E. On Behalf Of The Georgia Public Service Commission Public Interest Advocacy Staff, Before The Georgia Public Service Commission In The Matter Of: Georgia Power Company's Twenty-Second Semiannual Vogtle Construction Monitoring ("VCM")", Report Docket No. 29849, 5 June 2020, see https://www.powermag.com/wp-content/uploads/2020/06/29849-22vcm-d-grace-pd.pdf, accessed 1 July 2020.

751 - Ibidem.

752 - Ibidem.

753 - Ibidem.

754 - Georgia Public Service Commission, 5 June 2020, op. cit.

> testing the component), or others' performance (e.g., a fabrication failure beyond the scope of what the quality documentation would be able to detect)."[755]

VMG concluded that in terms of Southern's project planning and construction schedule performance for Vogtle-3 and -4: "Simply stated, it is to develop an unachievable plan, fail relatively quickly, and repeat the process to develop a new (and still unachievable) plan."

Critics of the Vogtle project had long predicted that there would be delays and that costs would be much higher.[756] The original project cost approved by the Georgia Public Service Commission (PSC) was US$6.1 billion in 2009, which corresponds to a cost of US$2,440/kWe (gross), whereas the 2017 estimate of US$23 billion translates to a cost of US$9,200/kW. The revised 2018 estimates in the range of US$28 billion have increased costs to US$11,200/kW, a 4.6-fold increase over the approved original estimate.[757] 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$$_{2007}$4,000/kW (US$$_{2018}$4,800/kW).[758]

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 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, a Georgia Power residential customer using 1,000 kWh per month would have seen his/her 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.[759] But given the long timescale of the project, including planned operational life, the actual costs to ratepayers will be much higher.

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,

755 - Ibidem.

756 - For example, see NIRS,"MIT Nuke Study Uses Unsupportable Reactor Cost Estimates", Nuclear Information and Resource Service, Press Release, 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 et al., "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.

757 - 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.

758 - 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.

759 - 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.southernenvironment.org/news-and-press/press-releases/groups-intervene-in-vogtle-cost-proceedings-georgians-should-not-bear-finan, accessed 28 May 2019.

resulting in higher income streams for Georgia Power and therefore Southern. In reporting 2018 Southern earnings, CEO Thomas A. Fanning stated that

> 2018 was a banner year for Southern Company (...) All of our state-regulated electric and gas companies delivered strong performance

with full-year 2018 earnings of US$2.23 billion, compared with earnings of US$842 million in 2017.[760]

WNISR2019 reported extensively on the economics of the Vogtle project. The past year has not improved matters for ratepayers in Georgia. Expert witness to the PSC on 5 June 2020 reported

> 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.[761]

The prospect of a delay beyond 24 months is highly likely.

"In conclusion, ratepayers will pay substantially more both prior to and after the Units begin providing service due to the delays and cost overruns."

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."[762] 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. The Georgia PSC points out:

> This amount is more than 80 percent greater than the US$4.4 billion assumed at certification. This additional US$3.6 billion in rate base will increase ratepayer revenue requirements by approximately US$12 billion over the 60-year life of the Units and increase annual revenue requirements by an average of US$380 million and US$350 million during the first five and ten years in operation, respectively. In conclusion, ratepayers will pay substantially more both prior to and after the Units begin providing service due to the delays and cost overruns.[763]

An additional complicating factor has been the impact of COVID-19. As reported in June 2020, Southern warned shareholders of possible further delays as a result of the pandemic, with challenges including "the supply chain, high absentee rates and slower productivity. Georgia Power cut the 9,000-strong workforce to 7,000 to aid social distancing efforts and

760 - Southern Company, "Southern Company reports fourth-quarter and full-year 2018 earnings", 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.

761 - Georgia Public Service Commission , "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 In The Matter Of: Georgia Power Company's Twenty-Second Semiannual Vogtle Construction Monitoring ("VCM") Report Docket No. 29849, 5 June 2020, see https://www.eenews.net/assets/2020/06/09/document_ew_04.pdf, accessed 3 June 2020.

762 - Ibidem.

763 - Ibidem.

improve workflow."[764] In spite of the implementation of social distancing and mask-wearing rules, early July 2020, the construction site had registered 54 active COVID-19 cases.[765]

During the past year, as in previous years, the Vogtle construction schedule of Southern Company was challenged by expert witnesses. In 2019, PSC staff had concluded that "at this time the status of the Project is uncertain,"[766] with major uncertainties whether the target date of hot functional tests scheduled for Unit 3 on 31 March 2020 can be achieved. Fuel loading at that time was scheduled for 14 October 2020. As it turned out, as of 1 July 2020 hot testing has yet to be conducted. On 30 April 2020, Thomas Fanning, CEO of Georgia Power parent Southern Company, stated that, "cold hydro testing is planned to begin in June or July, with hot functional testing beginning in August or September."[767] This schedule changed again, when in June, Southern announced that cold testing would take place "this fall" to then be followed by hot testing. Credit-rating agency Moody's said in a statement: "The unexpected, late-stage changes to these planned activities is credit negative for Georgia Power because it signals that challenges with the project continue, increasing the likelihood of additional cost overruns and further schedule delays."[768] With these delays, the schedule for fuel loading which in February 2020 was pushed back from October 2020 to November 2020, also appears in doubt.[769]

Multiple lawsuits against the Vogtle project initiated over the years have continued through the courts. As reported in WNISR2018, on 13 February 2018 a coalition of groups filed in Fulton County Superior Court a complaint challenging the Georgia PSC decision, declaring that it was unlawful, violating the PSC's own guidelines and Georgia state law.[770] On 21 December 2018, the court found that dissatisfied customers cannot raise concerns about the unfairness of Georgia PSC's process "until 2022 or later, after the project is complete… The court dismissed the appeal on technical grounds without addressing its substance," attorney Kurt Ebersbach of Southern Environmental Law Center (SELC) stated.[771] "The people of Georgia have been pre-paying for this mismanaged project since 2011, while the price tag has ballooned and the project timeline has slipped again and again," Liz Coyle, executive director of Georgia Watch,

764 - Kristi E. Swartz, "'Aggressive' timeline may actually delay Plant Vogtle", *E&E News*, 9 June 2020, see https://www.eenews.net/energywire/2020/06/09/stories/1063355257, accessed 4 July 2020.

765 - Jozsef Papp, "More than 50 active COVID-19 cases at Plant Vogtle", *The Augusta Chronicle*, 8 July 2020.

766 - Georgia PSC, "Public Disclosure—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—In The Matter Of Georgia Power Company's Nineteenth Semi-Annual Vogtle Construction Monitoring Report", Testimony Before The Georgia Public Service Commission, Docket No. 29849, 30 November 2018.

767 - *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.

768 - S&P Global, "Resequencing of Vogtle nuclear plant expansion activities is credit negative: Moody's", 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.

769 - Nuclear Regulatory Commission, "Vogtle Electric Generating Plant, Unit 3; Hearing Opportunity Associated With Inspections, Tests, Analyses, and Acceptance Criteria", Docket No. 52–025, NRC–2008–0252, Federal Register/Vol. 85, No. 29, 12 February 2020.

770 - Dave Williams, "Plant Vogtle opponents appeal vote to complete nuclear project", *Atlanta Business Chronicle*, 12 February 2018, see https://www.bizjournals.com/atlanta/news/2018/02/12/plant-vogtle-opponents-appeal-vote-to-complete.html, accessed 28 May 2019.

771 - *Albany Herald*, "Groups Challenge Court Decision Regarding Plant Vogtle Over Cost Concerns", as published by Georgia Watch, 10 January 2019, see https://www.georgiawatch.org/groups-challenge-court-decision-regarding-plant-vogtle-over-cost-concerns/, accessed 28 May 2019.

said. "Unless the court reverses the commission's decision, Georgia Power customers remain exposed to significant financial risk with seemingly no end in sight."[772]

In October 2019, the Court of Appeals remanded the case back to the lower Court to determine whether the citizens groups had met their burden to show that postponing their appeal until after the project is finished would not provide them an adequate remedy.[773] In April 2020, Fulton County Court ruled that it lacked jurisdiction to consider the merits of the case until the reactors' construction is finished.[774]

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 a NRC License Amendment request from Southern.[775] 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.[776] 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."[777] During a preliminary oral hearing of Southern's License Amendment request, the case was heard by the NRC's Atomic Safety and Licensing Board on 1 July 2020.

Vogtle Federal Loan Guarantees

Under the terms of the Department of Energy (DOE) Loan Guarantee Program, owners of nuclear projects are able to 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 rates, 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

772 - Ibidem.

773 - Georgia Watch, "Georgia Court Of Appeals Sends Plant Vogtle Challenge Back To Fulton County Superior Court", 30 October 2019, see https://georgiawatch.org/georgia-court-of-appeals-sends-plant-vogtle-challenge-back-to-fulton-county-superior-court/, accessed 4 July 2020.

774 - Southern Environmental Law Center, "Fulton County Superior Court Again Rules that Flawed Decision to Continue Vogtle Project May Not be Challenged Until Project is Finished", 21 April 2020, see https://www.southernenvironment.org/news-and-press/press-releases/court-again-rules-that-flawed-decision-to-continue-vogtle-project-may-not-be-challenged-until-project-is-finished, accessed 4 July 2020.

775 - BREDL, "BREDL And Our Chapter Concerned Citizens Of Shell Bluff File Petition Regarding Plant Vogtle Plant 3 License Amendment And Exemption", 12 May 2020, see http://www.bredl.org/nuclear/200511_BREDL_Petition_to_Intervene_Vogtle_3.htm; and U.S.NRC, "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, In the Matter of Southern Nuclear Operating Co. License Amendment Application for Combined Licenses NPF-91, Vogtle Electric Generating Plant Unit 3, Docket No. 52-025-LA-3, NRC-2008-0252, 11 May 2020, see http://www.bredl.org/pdf6/200511_BREDL_Petition_to_Intervene_Vogtle_3_Docket_52-025-LA-3.pdf, both accessed 4 July 2020.

776 - BREDL, "Residents Fight to Bring Case Against Georgia Nuclear Plant Legal Brief", 15 June 2020, see http://www.bredl.org/press/2020/200615_PR_Reply_Filed_VEGP-3_Plant_Sinking.pdf, accessed 4 July 2020.

777 - Ibidem.

> technologies that will catalyze the deployment of future projects that replicate or extend a technological innovation.[778]

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 nuclear plants being built in the U.S. in the coming decades. Oglethorpe Power Corporation (OPC), which has a 30 percent stake in Vogtle, confirmed in August 2017 that it had submitted a request to DOE for up to US$1.6 billion in additional loan guarantees. The company already had a US$3 billion loan guarantee from DOE. The other owners, Georgia Power and Municipal Electric Authority of Georgia (MEAG), have secured US$8.3 billion in separate loan guarantees from DOE since 2010, when they were approved by the Obama administration. Both of these 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.[779] A decision on terminating the Vogtle project would raise the prospect of repayment of the previous US$8.3 billion loan to Southern.[780] 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.[781] This brings the total loan guarantees provided for the Vogtle project by the DOE to US$12.03 billion.[782]

778 - 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.

779 - 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.

780 - 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.

781 - 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 10 May 2019.

782 - 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.

Ongoing Fallout from Termination of V.C. Summer Project

"The object of the conspiracy was for the defendant, Stephen Andrew Byrne, and others, through SCANA, to provide false representations and omit necessary facts in disclosures to the PSC, the ORS, the South Carolina State Government, the media, and to customers, so that the construction of the Nuclear Project would continue, minimizing regulatory risk, and avoiding state government oversight, all to defraud customers through inflated bills."[783]

United States Vs SCANA CEO Stephen Andrew Byrne – Plea Agreement, Criminal No 3:20 355 District of the United States for the District of South Carolina Columbia Division, 8 June 2020

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, during the past year has seen ongoing financial and legal fallout for the companies and ratepayers of South Carolina. 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—a 75 percent increase over initial estimates.[784]

On 27 February 2020, a lawsuit over the V.C. Summer project was filed by the U.S. Securities and Exchange Commission (SEC) against SCANA executives and Dominion Energy South Carolina, Inc. The lawsuit concerned securities fraud perpetrated by senior executives of SCANA over the V.C. Summer project. As the filing from SEC explained, from 2015 through 2017,

> construction of the new nuclear units at V.C. Summer was a tale of two projects. Publicly, SCANA touted progress being made on the project in its periodic filings with the SEC, on earnings calls with financial analysts, in press releases and video presentations, and in filings and testimony before the South Carolina Public Service Commission ("PSC"). These false statements enabled SCANA to bolster its stock price, sell $1 billion in corporate bonds at favorable rates, and obtain regulatory approval to charge its customers more than $1 billion in increased rates to help finance the project. Internally, however, SCANA knew that – contrary to its public statements – the project was significantly delayed, the construction schedule was unreliable and unachievable, and the company was unlikely to qualify for $1.4 billion in federal production tax credits because the new units would not be completed by the

783 - District of the United States for the District of South Carolina Columbia Division, "United States Vs Stephen Andrew Byrne – Plea Agreement", Criminal No 3:20 355, 8 June 2020, see https://srswatch.org/wp-content/uploads/2020/06/Byrne-court-plea-June-8-2020.pdf, accessed 6 July 2020.

784 - Robert Walton, "SCANA agrees to settle $2B class action suit over nuclear costs", *Utility Dive*, 26 November 2018, see https://www.utilitydive.com/news/scana-agrees-to-settle-2b-class-action-suit-over-nuclear-costs/542911/, accessed 26 May 2019.

> January 1, 2021 deadline for receiving the tax credits. SCANA and its senior management knew that the expansion project was not viable without those tax credits.[785]

The February 2020 filing by SEC included evidence of how SCANA "executives privately harbored dire concerns about the biggest project their company had ever undertaken and how they publicly sought to convince regulators and investors that everything was under control…" while knowing that there, "was [g]onna be a blood letting the likes of which we have never seen."[786] One SCANA executive concluded, "We got on our jet airplanes and flew around the country showing the same damn construction pictures from different angles and played our fiddles while the whole mf [sic] was going up in flames."

"The members of the conspiracy's actions and the associated cover-up allowed the project to continue until the contractor went bankrupt and the project was abandoned, resulting in billions of dollars of loss"

While the SEC filing was not a criminal proceeding, one was expected. On 8 June 2020, a plea filing agreement to U.S. District Court in Columbia stated that SCANA CEO Stephen Byrne orchestrated a cover-up of costly errors at the V.C. Summer nuclear site and "deceived regulators and customers in order to maintain financing for the project and to financially benefit SCANA… As construction problems mounted, costs rose, and schedules slipped, the defendant Stephen A. Byrne, and others, hid the true state of the project".[787] The filing said: "The members of the conspiracy's actions and the associated cover-up allowed the project to continue until the contractor went bankrupt and the project was abandoned, resulting in billions of dollars of loss."[788] While the information doesn't say that all top SCANA officials were part of the conspiracy, the court documents assert that leading the "failed effort to construct two nuclear power generators in Fairfield County" were "executives, employees and the lawyers who advised them." As reported in WNSIR18 onwards, the FBI and prosecutors in the U.S. Attorney's Office since 2017 have been investigating the V.C. Summer nuclear plant project. The prospects are that other officials will be charged.

The June 2020 filing states that Stephen Byrne and other officials

> represented to regulatory agencies that V.C. Summer Units 2 and 3 would be operational in 2019 and 2020, when in truth members of the conspiracy had hired Bechtel to evaluate the project; Bechtel found the Nuclear Project to be significantly off schedule and over-budget.

785 - United States District Court District Of South Carolina Columbia Division, "UNITED States Securities And Exchange Commission, Plaintiff, V. Scana Corporation, Dominion Energy South Carolina, Inc. (f/k/a South Carolina Electric & Gas Company), Kevin B. Marsh, And Stephen A. Byrne, Defendants", 27 February 2020, see https://bloximages.newyork1.vip.townnews.com/postandcourier.com/content/tncms/assets/v3/editorial/b/ca/bca4c31c-59bf-11ea-8609-5f7574a496f2/5e585c9cc4fec.pdf.pdf; and *Post and Courier*, "SCANA and former execs sued by SEC for 'fraud' over failed SC nuclear project", 27 February 2020, see https://www.postandcourier.com/business/scana-and-former-execs-sued-by-sec-for-fraud-over-failed-sc-nuclear-project/article_93fa2116-59a9-11ea-a3e4-a31678d9c119.html, both accessed 6 July 2020.

786 - United States District Court District Of South Carolina Columbia Division, "UNITED States Securities And Exchange Commission, Plaintiff, V. Scana Corporation, Dominion Energy South Carolina, Inc. (f/k/a South Carolina Electric & Gas Company), Kevin B. Marsh, And Stephen A. Byrne, Defendants", 27 February 2020, see https://bloximages.newyork1.vip.townnews.com/postandcourier.com/content/tncms/assets/v3/editorial/b/ca/bca4c31c-59bf-11ea-8609-5f7574a496f2/5e585c9cc4fec.pdf.pdf, accessed 6 July 2020.

787 - In the District of the United States for the District of South Carolina Columbia Division, "United States Vs Stephen Andrew Byrne – Plea Agreement", Criminal No 3:20 355, 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.

788 - Ibidem.

> Members of the conspiracy never provided this information to the regulatory agencies... When Bechtel provided data demonstrating that the Nuclear Project was failing catastrophically, bifurcated, edited, and buried the Bechtel report(s) and the information contained within under disingenuous representations of attorney-client privilege.[789]

The conspiracy to deceive allowed 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 the filings.[790] Under legislation passed by the South Carolina Public Services Commissioners in 2008—but strongly opposed by civil society groups—construction costs for the V.C. Summer reactors were to be paid by state ratepayers. The former SCANA CEO in the June-2020 plea agreement promised to cooperate with federal law enforcement and testify, "before any grand juries and at any trials or other proceedings if called upon to do so...." A plea hearing was scheduled for July 2020.[791]

The fraud scandal has extended to Dominion Energy, which took over SCANA in January 2019, at which time it inherited the company's legal liability, along with all of SCE&G's ratepayers in South Carolina. Dominion Energy South Carolina, along with former SCANA officials, were named in the February 2020 lawsuit filed by the SEC.[792] Since when the utility had been seeking to recuse itself from the proceedings by settling the case without admitting any fraud by SCANA. In May 2020, it was reported that agreement was near to being reached whereby Dominion would pay a US$25 million settlement with the SEC.[793] As trade journal *Nucleonics Week* reported in June 2020, Dominion had entered into a cooperation agreement with the U.S. Attorney Office's Office of South Carolina and the South Carolina Attorney General 27 December 2018, according to an attachment to the 8 June 2020 filing.[794] In its takeover of SCANA, Dominion "has committed to make extensive remedial efforts to redress ratepayers," which is estimated to be approximately US$4 billion. 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.[795] The 8 June 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".[796]

In a related matter, on 3 June 2020 Dominion Energy agreed to pay upwards of US$192.5 million in reparations to former SCANA investors following a shareholder lawsuit-settlement over the

789 - Ibidem.

790 - Ibidem.

791 - *Lexington Chronicle*, "Ex-SCE&G Exec Faces 5 Years In Prison", 5 July 2020, see https://www.lexingtonchronicle.com/news/ex-sceg-exec-faces-5-years-prison, accessed 6 July 2020.

792 - *Post and Courier*, "SCANA and former execs sued by SEC for 'fraud' over failed SC nuclear project", 27 February 2020, see https://www.postandcourier.com/business/scana-and-former-execs-sued-by-sec-for-fraud-over-failed-sc-nuclear-project/article_93fa2116-59a9-11ea-a3e4-a31678d9c119.html, accessed 6 July 2020.

793 - *Post and Courier*, "Dominion close to settling case with securities regulators over SC nuclear project", 8 May 2020, see https://www.postandcourier.com/business/dominion-close-to-settling-case-with-securities-regulators-over-sc-nuclear-project/article_9a4244fa-9148-11ea-8762-87d6c73e0964.html, accessed 6 July 2020.

794 - *NW*, "Former Summer executive to plead guilty to fraud", 11 June 2020.

795 - *Post and Courier*, "Ex-SCE&G official will cooperate as witness in criminal probe of failed VC Summer project", 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.

796 - Ibidem.

V.C. Summer project.[797] The termination of the V.C. Summer reactor project and revelations about years of cover-ups by SCANA led to the collapse of the company's stock value which was a factor in the takeover by Dominion. Dominion officials do not have to admit to fraud or false pretenses of their former buyout as part of the settlement.

The cancellation of the V.C. Summer project adds to the history of 40 other stranded nuclear reactor projects in the United States whose construction started in the 1970s and which were abandoned between 1977 and 1989.

Securing Subsidies to Prevent Closures

As WNISR has reported in recent years, utilities have been actively lobbying for state legislation and contracts that would provide significant financial support for their reactor operations (for details see Table 10 and WNISR2018 Annex 4). As of 1 July 2020, legislation in five states (Connecticut, Illinois, New Jersey, New York and Ohio) had been enacted, which in total provide state subsidies to 13 reactors at ten nuclear plants. All of these five state states have unbundled, retail-choice electricity markets, where generators do not receive cost recovery from state regulatory commissions. These account for 9 percent of the utility-scale generating capacity in those five states and 13 percent of the U.S. nuclear generating capacity.[798]

Central to the future of nuclear power in the Pennsylvania-New Jersey-Maryland Interconnection LLC (PJM) wholesale electricity market are the rules expected to be proposed by the Federal Energy Regulatory Commission (FERC).[799] In June 2018, FERC invalidated the PJM market rules.[800] The FERC order relates to how the PJM sets the price of capacity it procures through its capacity market, known as the Reliability Pricing Model (RPM). They will affect how state subsidies, including ZECs, will be considered in the wholesale market. At issue is whether the subsidies being received by utilities for their nuclear plants will be factored into the capacity auction pricing. As reported in WNISR, much of the legislation passed in the five states has been Zero Emission Credits or ZECs, which have evolved from small-scale renewables to thousands of megawatts from larger nuclear units. FERC has noted that "With each such subsidy, the market becomes less grounded in fundamental principles of supply and demand."[801]

797 - Class Action Lawsuit Center, "SCANA Corporation (NYSE: SCG) Now (NYSE:D) Shareholder Lawsuit Settlement", 3 June 2020, see https://classactionlawsuitcenter.com/securities-settlements/scana-corporation-nyse-scg-now-nysed-shareholder-lawsuit-settlement/, accessed 6 July 2020.

798 - U.S. EIA, "Five states have implemented programs to assist nuclear power plants", US. Energy Information Agency, 7 October 2019, see https://www.eia.gov/todayinenergy/detail.php?id=41534, accessed 7 July 2020.

799 - 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.

800 - 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

801 - 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, Federal Energy Regulatory Commission, issued 29 June 2018, see https://www.ferc.gov/CalendarFiles/20180629212349-EL16-49-000.pdf, accessed 30 May 2019.

Table 10 · U.S. State Emission Credits for Uneconomic Nuclear Reactors 2016–2019 (as of 1 July 2020)

State	Utility	Reactors	Permanent Closure		Status of Emissions Credit Legislation	Value	Legal Status
			Planned Date	Planning Status			
Illinois	Exelon	Clinton-1	June 2017	Repealed	Illinois Future Energy Jobs Act passed by legislature – June 2016	US$16.50/MWh (US$200 million a year)	ZEC Upheld in Court[a]
		Quad Cities-1 & -2	June 2018	Repealed			
New Jersey	PSEG/Exelon	Salem-1 & -2	Threatened by 2019	Likely to be repealed	Legislature passed – April 2018 (reactors with operating license through 2030 only)	US$300 million a year[b]	Legal challenge filed[c]
	PSEG	Hope Creek	Threatened by 2019	Likely to be repealed	Eligible		
Connecticut	Dominion	Millstone-2 & -3	Threatened – no date	Repealed	Senate Zero Carbon Procurement Act approved by Governor November 2017[d]	US$330 million a year	N/A
New York	Exelon	Fitzpatrick	Threatened	Likely to be repealed	NYPSC Clean Energy Standard ZEC passed in 2016	US$482 million 2018–2019; US$8 billion 2017–2029	N/A
	Entergy	Ginna	Threatened	Likely to be repealed			
		Nine Mile Point-1	Threatened	Likely to be repealed			
Ohio	FirstEnergy	Davis Besse	May 2020	Repealed [e]	Legislation passed as of 27 July 2019	US$150 million per year	N/A
		Perry	May 2021				

Sources: Various, compiled by WNISR, 2020

Notes:

PSEG: Public Service Enterprise Group; ZEC: Zero Emission Credits; NYPSC: New York State Department of Public Service.

a - See Pamela King, "The fight's not over yet on state nuclear credits", *E&ENews*, 16 April 2019, see https://www.eenews.net/stories/1060166933.

b – Christen Smith, "NJ Approves $300M ZECs for Salem, Hope Creek Nukes", *RTO Insiders*, 19 April 2019, see https://rtoinsider.com/nj-approves-zecs-nukes-114741/, accessed 15 July 2019.

c – Talia Buford, "New Jersey's $300 Million Nuclear Power Bailout Is Facing a Court Challenge. Does It Have a Chance?", *ProPublica*, 16 May 2019, see https://www.propublica.org/article/new-jerseys-300-million-nuclear-power-bailout-is-facing-a-court-challenge-does-it-have-a-chance, accessed 13 July 2019.

d - Robert Walton, "Dominion threatens Millstone closure if plant shut out of support program", *Utility Dive*, 10 July 2018, see https://www.utilitydive.com/news/dominion-threatens-millstone-closure-if-plant-shut-out-of-support-program/527364/, accessed 12 July 2018.

e - First Energy has announced that it will begin the process to rescind the deactivation orders for its Perry and Davis-Besse reactors. See FirstEnergy Solutions, "FirstEnergy Solutions Applauds Enactment of HB6 Legislation", 24 July 2019.

In December 2019, FERC released an order[802] directing PJM[803] to significantly expand its minimum offer price rule (MOPR) to mitigate the impacts of state-subsidized resources on the capacity market. The ruling has the potential to undermine renewable energy development and as such is likely to be legally challenged by renewable energy industry associations and environmental groups, which are particularly concerned about the ruling's de-facto support for continued fossil fuel use.[804] It was utilities with significant nuclear capacity that were most

802 - FERC, "Order Establishing Just And Reasonable Rate", United States Of America Federal Energy Regulatory Commission, 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.

803 - 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.

804 - 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.

concerned by the FERC ruling. Dependent on capacity market revenues, ZECs or equivalent, exist in Connecticut, Illinois, New Jersey, New York and Ohio and provide state subsidies to reactors. A total of nearly 8,000 MW of capacity exists in these states.

The long-expected FERC order did not offer an exemption for existing nuclear plants that currently receive state support. The FERC decision would require nuclear plants receiving state zero-emission credits and much other subsidized resources, including energy procured through a state renewable portfolio standard, to bid their capacity into PJM without factoring in the subsidies. That could raise their capacity market bid price leading to them to fail to clear the auction and thereafter stop receiving capacity market fees. Nuclear plants would have to bid into the capacity market at their net Avoidable Cost Rate (ACR), which equals a predetermined ACR, minus any expected net revenues from the energy and ancillary services markets.[805] The proposed ACR numbers (from 2018) show that nuclear had the highest possible ACR value of any technology, at US$631/MW-day.[806] If this number is set at a level too high, the result could be that the reactors do not clear the capacity market, with resulting risk of closure.[807] As noted in an analysis by Resources for the Future, the FERC order also applies to resources that are eligible to receive state subsidies, which potentially means reactors that currently do not receive state financing.[808]

Exelon, the largest nuclear reactor operator in the U.S. called the FERC decision "stunning", and that "by granting the request of fossil generators, this order completely undermines state clean and renewable energy programs and will cost thousands of jobs, increase air pollution and unnecessarily raise electricity bills by US$2.4 billion annually".[809]

The complex impact of the FERC ruling has been to raise questions over the future of the PJM capacity market, with the possibility of states deciding to withdraw from the regional market. At the very least, legal challenges to the ruling have already been filed, by state regulators, industry groups and environmental organizations. In one filing, the Natural Resources Defense Council (NRDC), Sierra Club, Environmental Defense Fund, and the Union of Concerned Scientists are challenging FERC over its de-facto bailout of coal and gas power plants at the expense of state clean energy policies.[810]

805 - Kathryne Cleary, "What the Minimum Offer Price Rule (MOPR) Means for Clean Energy in PJM", *Resources*, 21 January 2020, see https://www.resourcesmag.org/common-resources/what-minimum-offer-price-rule-mopr-means-clean-energy-pjm/#:~:text=In%20December%202019%2C%20the%20Federal,resources%20on%20the%20capacity%20market, accessed 7 July 2020.

806 - Ibidem.

807 - Ibidem.

808 - Ibidem

809 - Exelon, "Exelon Statement on FERC's Minimum Offer Price Rule Order", 19 December 2019, see https://www.exeloncorp.com/newsroom/media-statement-on-ferc-mopr, accessed 7 July 2020; and *Nucleonics Week*, "Subsidized resources face challenges in Eastern capacity markets: analysts", 9 January 2020.

810 - *PowerMag*, "Mixed Reactions to FERC's Recent MOPR Order from Power Generators", 26 December 2019, see https://www.powermag.com/mixed-reactions-to-fercs-recent-mopr-order-from-power-generators/; and *Utility Dive*, "Broad array of groups sue FERC over PJM MOPR decision as Chatterjee rejects cost, renewable concerns", 27 April 2020, see https://www.utilitydive.com/news/broad-array-of-groups-sue-ferc-over-pjm-mopr-decision-as-chatterjee-rejects/576478/; and EarthJustice, "FERC Sued over Unlawful Rule That Props Up Gas, Coal Plants", 21 April 2020, see https://earthjustice.org/news/press/2020/ferc-sued-over-unlawful-rule-that-props-up-gas-coal-plants, all accessed 7 July 2020.

The U.S. Energy Information Agency reported in autumn 2019 that additional state support will likely only apply to about 30 percent of the U.S. nuclear fleet, or those plants located in retail-choice or wholesale power markets.[811]

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 a decision to reverse the decision to close the Beaver Valley Units 1 and 2. Plant owner Energy Harbor Corp. notified the PJM Interconnection grid operator that it would rescind its March 2018 deactivation notices. The reactors were owned previously by Energy Solutions 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. "The decision to rescind the deactivations for Beaver Valley was largely driven by the efforts of Governor Wolf's administration to join the Regional Greenhouse Gas Initiative... and will begin to help level the playing field for our carbon-free nuclear generators" and will help it market "carbon free energy" to customers", said Energy Harbor President and Chief Executive Officer John Judge on 13 March 2020.[812] 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.[813] Carbon allowances were sold at US$5.65 per ton in the RGGI's most recent quarterly auction.[814] The states that are in the RGGI are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, Vermont and New Jersey; Virginia in early 2020 passed a law that paves the way for it to join.

Conclusions and Prospects for Nuclear Power in an Election Year

The nuclear power issue in the U.S. remains centered around the relentless efforts of the industry and their supporters to gain financial assistance for lifetime extensions of their ageing reactor fleet, increasingly struggling in a competitive electricity market with low prices, flat consumption (at best) and ferocious rivals in the renewable energy sector. These efforts, as of July 2020, are currently suffering a severe backlash with the massive corruption scandal involving key industry and political leaders unfolding in the state of Ohio. This is likely to lead not only to the reversal of large subsidies that had been allocated to the involved nuclear utilities but also has the potential to cascade to other states and undermine similar efforts to secure financing.

811 - Ibidem.

812 - State Impact Pennsylvania, "Owners of Pa.'s Beaver Valley nuclear power station will keep it open because of state's climate plan", 13 March 2020, see https://stateimpact.npr.org/pennsylvania/2020/03/13/owners-of-pa-s-beaver-valley-nuclear-power-station-will-keep-it-open-because-of-states-climate-plan/, accessed 6 July 2020; and *DailyEnergyInsider*, "Energy Harbor Corp rescinds deactivation of Beaver Valley nuclear power facility", 18 March 2020, see https://dailyenergyinsider.com/news/24695-energy-harbor-corp-rescinds-deactivation-of-beaver-valley-nuclear-power-facility/, accessed 25 July 2020.

813 - 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.

814 - *PowerMag*, "Pennsylvania Move to Join RGGI May Save Nuclear Plant", 15 March 2020, see https://www.powermag.com/pennsylvania-move-to-join-rggi-may-save-nuclear-plant/, accessed 6 July 2020.

The other industry focus is the desperate attempt to complete the construction of the two AP1000 units at the Vogtle site that has been struggling for years with delays and cost overruns, and now was hit by the COVID-19 pandemic (see Nuclear Power in the Age of COVID-19).

Finally, there is some industry hope for generous federal support for various programs aiming at the development of a set of new reactor types and for a rapid move into practical realizations. However, considering the difficulties the industry has been illustrating in delivering the first couple of so-called Generation III reactors and the past history of failed efforts to get a new generation of "advanced reactor designs" off the ground, the outlook for a significant shift to success is rather bleak.

The immediate prospects for nuclear power in the coming few years are unlikely to change as a result of the Presidential election in November 2020. While there are differences in degrees of support for nuclear power between the Republican and Democratic Parties, in reality there has been bi-partisan support for some form of nuclear power amongst the leading Members of the U.S. House of Representatives and the Senate. Policy on nuclear energy in both chambers of Congress is not generally a point of division between the two parties. There are active supporters as well as critics in both parties. The fact that nuclear energy retains political support within the leadership of both parties is a reflection of the continuing influence of the nuclear industry at state level and in Washington DC.

In March 2020, the U.S. Senate voted on the American Energy Innovation Act of 2020, proposed as bi-partisan bill and the first comprehensive update to U.S. energy policy since 2008. While supporting renewable energy development, the proposed legislation also backed advanced nuclear power, as well as gas fracking and new oil extraction. Despite being proposed by leading Republicans and Democrats in the Senate, it failed to secure sufficient votes.

Potentially more significant to the prospects of nuclear power in the U.S. is the Nuclear Energy Leadership Act (NELA) (H.R. 3306). Some of its key provisions include providing for at least two advanced nuclear reactor demonstration projects to be completed by the end of 2025 and revising federal energy contracting authority so the Government can enter into Power Purchase Agreements for up to 40 years, which in the words of Democratic House member Luria, would be "better reflecting the length of time that nuclear power offers a return on investment." NELA, included in the National Defense Authorization Act for Fiscal Year 2021 (NDAA, S 4049) by Senate Republican Lisa Murkowski and Democrat Cory Booker, was passed in July 2020, but it remains unclear whether it will be included in final legislation to be voted on by both House and Senate.

Similarly, in legislation passed in July 2020 by the Democrat-controlled House of Representatives, the Appropriations Committee approved fiscal year 2021 spending legislation for the Department of Energy (DOE). The legislation, if approved in the Senate, would provide billions of dollars in one-time "emergency" funding to DOE, citing a need to support economic recovery from the coronavirus pandemic. For the Office of Nuclear Energy, the bill includes US$700 million for its new Advanced Reactor Demonstration program, US$192 million for its Advanced SMR program, US$100 million for integrated hydrogen-nuclear demonstration projects, and US$125 million for recapitalization of the Advanced Test Reactor at Idaho National Lab. The Chair of the House Appropriations Committee, a Democrat, for example supports the long-term operation of the Davis-Besse reactors, including the recent DOE program to install an electrolysis unit at the plant to demonstrate hybrid hydrogen energy production.

The consequences of the potential defeat for Donald J Trump in the November 2020 Presidential elections and a victory for Democratic Party candidate Joseph Biden cannot be considered in simple terms as a downside for the prospects of nuclear power in the U.S. Presidential hopeful Joe Biden's US$2 trillion clean energy plan, designed to achieve a carbon emissions-free energy sector by 2035, includes keeping existing nuclear energy plants in operation. The plan itself is more circumspect on what it actually means for continued operation of reactors in the U.S. In the section on the future of nuclear energy, Biden's plan states support for "advanced nuclear" and SMRs, but without providing any details. Support for nuclear is framed in the context of climate change "to address the climate emergency threatening our communities, economy, and national security, we must look at all low- and zero-carbon technologies". That's why Biden will support a research agenda to look at issues ranging from cost to safety to waste disposal systems, that remain an ongoing challenge with nuclear power today. Biden also plans to establish an Advanced Research Projects Agency (ARPA) with the aim of securing a 100%-clean-energy target, based upon technologies including, "small modular nuclear reactors at half the construction cost of today's reactors." Given the many obstacles that are likely to prevent such economics for SMRs, it remains unclear what this actually means in the real world.

FUKUSHIMA STATUS REPORT

INTRODUCTION

More than nine years have passed since the Fukushima accident occurred in March 2011 and the situation onsite is still not stabilized. Since WNISR2019, the medium- and long-term roadmap was revised again. Plans to retrieve more spent nuclear fuel and molten fuel debris have been further delayed. Tokyo Electric Power Company (TEPCO) and the Government state that storage capacity for contaminated water will reach capacity in 2022, while a government appointed panel recommended the release of the water into the environment.

Most of the remaining evacuation orders have not been lifted, and the return rate of evacuated residents has remained very low.

ONSITE CHALLENGES[815]

Current Status of Each Reactor

Water injection into the reactor pressure vessels of Units 1 to 3, which all contain fuel debris, is still ongoing. The temperature of the lower part of the reactor pressure vessel and the containment vessel is maintained at about 15–20 °C. The temperature in the spent fuel storage pool is kept at about 17–23 °C.[816] The air dose-levels of radiation have been mostly 10 µSv/h or less on the power plant site as a whole[817], but the levels are much higher near the reactor buildings; for example, in January 2020, the dose level between Units 3 and 4 was 1.7 mSv/h, 170 times higher than the site average.[818] Inside the building, for example at a location on the 2nd floor of Unit 1, levels of 280 mSv/h or higher were recorded.[819]

The removal of spent nuclear fuel from the pool at Unit 3 (a total of 566 fuel assemblies) started on 15 April 2019. As of March 2020, only 119 assemblies had been removed, while Units 1 and 2 have not got beyond the preparatory stage.

In September 2019, it was decided to start retrieving fuel debris with Unit 2,[820] as it was determined that Unit 2 was easier to access due to the unit's relatively low dose levels. The retrieved fuel debris will be put in storage cans and temporarily stored in a dry state. According

815 - In this section, unless indicated otherwise, the following reference is used: Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Summary of Decommissioning and Contaminated Water Management", METI, 27 March 2020, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/mp202003.pdf, accessed 27 April 2020.

816 - Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Plant parameters of the Fukushima Daiichi Nuclear Power Plant", Undated (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2020/03/1-1.pdf, accessed 4 May 2020.

817 - TEPCO, "Fukushima Daiichi Ground Survey Map (for March 5 and 6, 2020)", March 2020 (in Japanese), see https://www.tepco.co.jp/decommission/data/surveymap/pdf/2020/f1-sv-20200326-j.pdf, accessed 4 May 2020.

818 - TEPCO, "Fukushima Daiichi Survey Map (March 2020)", March 2020 (in Japanese), see https://www.tepco.co.jp/decommission/data/surveymap/pdf/2020/f1-sv-20200326-j.pdf, accessed 4 May 2020.

819 - TEPCO, "About air dose rate in the building (Unit 1, 1 January 2019–31 December 2019)", 3 April 2020 (in Japanese), see https://www.tepco.co.jp/decommission/data/surveymap/pdf/2020/sv-u1-20200403-j.pdf, accessed 4 May 2020.

820 - Nuclear Damage Compensation and Decommissioning Facilitation Corporation, "Technical Strategic Plan 2019 for the Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", 9 September 2019, see http://www.dd.ndf.go.jp/en/strategic-plan/book/20191101_SP2019eFT.pdf, accessed 4 May 2020.

to TEPCO's action plan, the removal will start during 2021.[821] Furthermore, according to TEPCO, the total amount allocated for this limited debris retrieval work is ¥1.37 trillion (US$1.28 billion[822]).[823]

In December 2019, the fourth revision of the medium- and long-term roadmap for decommissioning was published;[824] it reported that more than 4,650 fuel assemblies (mainly spent fuel, incl. around 8 percent fresh fuel) or roughly 790 tons are still stored in the pools[825] and that the timing of removal from the pools of Units 1 and 2 was delayed by 4–5 years and 1–3 years respectively. However, the goal to complete the decommissioning process between 2041 and 2051 was maintained (see Table 11).

Table 11 · Fukushima Decommissioning: Evolution of the Medium- and Long-Term Roadmap

		2019 edition	2017 edition	2015 edition
Fuel removal from spent fuel pools	Start of fuel removal from Unit 1	FY2027-FY2028	Around FY2023	FY2020
	Start of fuel removal from Unit 2	FY2024-FY2026	Around FY2023	FY2020
	Start of fuel removal from Unit 3	[Started April 2019]	Mid-FY2018	FY2017
	Completion of nuclear fuel removal for Units 1–6	During 2031	—	—
Fuel debris retrieval	Determination of fuel debris retrieval methods for each unit	—	—	Around two years from now
	Determination of fuel debris retrieval methods for the first scheduled unit	—	FY2019	First half of FY2018
	Start of fuel debris retrieval at the first scheduled unit	During 2021	During 2021	During 2021

Sources: Compiled by the author based on the following materials: Inter-Ministerial Council for Contaminated Water and Decommissioning Issues, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station", 2015, 2017 and 2019 editions.

Contaminated Water Management

TEPCO has continued to employ a variety of countermeasures against the further increase of contaminated water, including frozen soil walls, land-side impermeable walls,[826] and the pumping of groundwater.[827] Despite this, the company has not been able to prevent the further generation of contaminated water. The amount of contaminated water generated was about 180 m³/day on average in FY2019, which is higher than the 170 m³/day in FY2018 (it was about 470 m³/day in FY2014 before taking measures). The new roadmap set a target of

821 - TEPCO, "Medium- to Long-Term Decommissioning Execution Plan 2020", 27 March 2020 (in Japanese), see https://www.tepco.co.jp/decommission/information/newsrelease/reference/pdf/2020/1h/rf_20200327_1.pdf, accessed 4 May 2020.

822 - Exchange rate is US$1 = ¥107, as of May 2020.

823 - TEPCO, "Consolidated financial forecasts for FY2019", 30 March 2020 (in Japanese), see https://www.tepco.co.jp/press/release/2020/pdf1/200330j0301.pdf, accessed 4 May 2020.

824 - Inter-Ministerial Council for Contaminated Water and Decommissioning Issues, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station", 27 December 2019, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20191227_3.pdf, accessed 4 May 2020.

825 - Fuel assemblies stored in each pool: 392 for Unit 1, 615 for Unit 2, 447 for Unit 3, 0 for Unit 4, 1,542 for Unit 5, 1,654 for Unit 6. See Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Summary of Decommissioning and Contaminated Water Management", 27 March 2020, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/mp202003.pdf, accessed 27 April 2020.

826 - An ice wall is made by circulating a refrigerant at approximately –30 °C) in the piping buried underground to freeze the soil containing groundwater.

827 - Generic term for water contaminated with radioactive substances such as seawater injected at the time of the accident and groundwater flowing into the building basements.

150 m³/day by 2020 and 100 m³/day by 2025. A total of 62 radionuclides were targeted for removal, including Strontium-90. The technology used however, did not perform as claimed by TEPCO. Consequently, in 2018 TEPCO admitted that 80 percent of the contaminated water would have to undergo further processing to reduce concentrations of radionuclides such as strontium and iodine. TEPCO has not deployed any technology for tritium removal.

The contaminated water continues to be stored on site. The cur

rent storage tank plan has a capacity of 1.37 million m³ and is expected to be saturated by the end of 2022.[828] The Ministry of Economy, Trade and Industry (METI) spent three years discussing the treatment of tritiated water not only from a technical point of view but also from a social point of view such as reputational damage. The ministry's final report, published in February 2020, presented two possibilities: diluting the tritiated water and releasing it into the ocean or converting it into steam and releasing it into the atmosphere. The report said that both methods may cause reputational damage, so the Government should take prompt action.[829] Recommended measures include the following:

- Radionuclides other than tritium should be treated by secondary purification.
- The starting time of disposal, disposal volume, period for disposal, and levels of concentration at the time of disposal should be determined appropriately, taking into account the opinions of the parties concerned.
- Efforts to strengthen monitoring of the surrounding environment and to disclose the monitoring results in an easy-to-understand manner are important.
- Risk communication measures to convey information accurately as well as countermeasures to prevent, neutralize, and compensate the reputational damage should be enlarged and strengthened.[830]

The IAEA has also stated that both of the water management options would be technically feasible and has advised that "a decision (...) must be taken urgently, engaging all stakeholders".[831]

TEPCO has published a draft proposal based on METI's position.[832] According to the company, as of March 2020, the number of tanks is 979, the storage capacity is about 1.19 million m³, and the total amount of tritium is about 860 trillion becquerels.[833] TEPCO argued that no matter which option the company selects, it will adopt a method that does not release a large amount

828 - TEPCO, "Regarding our draft proposal in response to the Report of the Subcommittee on the Handling of the ALPS Treated Water", 24 March 2020 (in Japanese), see https://www.tepco.co.jp/decommission/progress/watertreatment/images/200324.pdf, accessed 4 May 2020.

829 - Subcommittee on Handling of the ALPS Treated Water, "The Subcommittee on Handling of the ALPS Treated Water Report", Provisional Translation, METI, 10 February 2020, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20200210_alps.pdf, accessed 4 May 2020.

830 - Ibidem, p.51–52.

831 - IAEA, "IAEA Follow-up Review of Progress Made on Management of ALPS Treated Water and the Report of the Subcommittee on Handling of ALPS treated water at TEPCO's Fukushima Daiichi Nuclear Power Station", Review Report to the Government of Japan, 2 April 2020, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/4fu-report.pdf.

832 - TEPCO, "Regarding our draft proposal in response to the Report of the Subcommittee on the Handling of the ALPS Treated Water", 24 March 2020 (in Japanese), see https://www.tepco.co.jp/decommission/progress/watertreatment/images/200324.pdf, accessed 4 May 2020.

833 - If the amount of tritium released into the seawater before the Fukushima accident is assumed as 2 trillion Bq per year, it means that 430 years' worth of tritium is currently stored.

at any one time, guided by the conventional concentration limit (5 Bq/L in the atmosphere, or 60,000 Bq/L in seawater).

The proposal to release the contaminated water into the environment has generated substantial opposition, extending from within Fukushima, including LDP controlled municipalities,[834] to wider civil society in Japan, as well as overseas from the Governments of the Republic of Korea[835] and China.[836] In May 2020, four UN Human Rights Special Rapporteurs raised their concerns over the implications for Fukushima citizens and the wider community.[837] A decision by the Government and a corresponding legislative proposal is expected in late 2020.[838]

Worker Exposure

TEPCO claims to have enough workers for decommissioning, but in reality, there are many challenges. The decommissioning work relies heavily on subcontractors, for example, as of March 2020, of the 6,978 decommissioning workers, only 917 (13 percent) were TEPCO employees while 6,061 (87 percent) are employees of subcontractors. Moreover, the maximum effective dose of external exposure in March 2020 was limited to 1.86 mSv for TEPCO employees but a dose almost eight times higher of 14.28 mSv was allowed for employees of partner companies.[839]

TEPCO actually seems to be lacking manpower. The company had expressed the idea of accepting "special skill foreign workers" for decommissioning work. However, this scheme of the Japanese Government is designed to allow foreigners to work in industries with labor shortages in Japan, such as the construction industry and agriculture, and does not include work that involves exposure to radiation. In the end, TEPCO withdrew this plan in May 2019 after the Ministry of Health, Labor and Welfare (MHLW) intervened.[840]

The MHLW is still conducting the epidemiological study of about 20,000 workers who were exposed to 100 mSv at the time of the Fukushima accident. However, according to a report released in March 2019, the survey had encountered difficulties due to the lack of participating

834 - *Fukushima Minpo*, "Fukushima localities speak out against dumping radioactive water in sea", as published by *The Japan Times,* 17 July 2020, see https://www.japantimes.co.jp/news/2020/07/17/national/fukushima-assemblies-radioactive-water/, accessed 20 July 2020.

835 - Mi Ock Mun, "Statement", Vice Minister of the Ministry of Science and ICT Head Delegate of the Republic of Korea, 63rd IAEA General Conference, 19 September 2019, see https://www.iaea.org/sites/default/files/19/09/gc63-korea-republic-of.pdf, accessed 20 July 2020.

836 - Greenpeace East Asia, "China, Korea and Chile challenge Japan over Fukushima contaminated water crisis at United Nations maritime meeting", 15 November 2019, see https://www.greenpeace.org/eastasia/press/2698/china-korea-and-chile-challenge-japan-over-fukushima-contaminated-water-crisis-at-united-nations-maritime-meeting/, accessed 20 July 2020.

837 - MOFA, "Response to the Joint Communication from four UN Special Rapporteurs from the Government of Japan concerning ALPS treated water at the TEPCO's Fukushima Daiichi Nuclear Power Station", Ministry of Foreign Affairs of Japan, 12 June 2020, see https://www.mofa.go.jp/fp/hr_ha/page4e_001067.html; and *Kyodo News*, "U.N. experts urge Japan not to rush discharge of radioactive water", 9 June 2020, see https://english.kyodonews.net/news/2020/06/6f6afd14d6a4-un-experts-urge-japan-not-to-rush-discharge-of-radioactive-water.html, both accessed 20 July 2020.

838 - *Kahoku*, "Fukushima Daiichi Nuclear Power Plant's Treated Water Disposal Law Decided to be delayed after autumn", 25 June 2020 (in Japanese), see https://www.kahoku.co.jp/special/spe1090/20200625_01.html.

839 - TEPCO, "Evaluation of the exposure dose of workers at the Fukushima Daiichi Nuclear Power Station", 24 April 2020 (in Japanese), see https://www.tepco.co.jp/decommission/information/newsrelease/exposure/pdf/2020/exposure_20200424-j.pdf, accessed 4 May 2020.

840 - TEPCO, "Response to the notification from the Ministry of Health, Labor and Welfare about thoroughly ensuring the occupational safety and health of foreign workers at Fukushima Daiichi Nuclear Power Station", 22 May 2019 (in Japanese), see https://www.tepco.co.jp/press/news/2019/1515153_8967.html, accessed 4 May 2020.

subjects, and the researchers had not been able to reach a conclusion. Of the 19,808 study subjects, only 7,270 (36.7 percent) participated in the study; 3,334 (16.8 percent) refused to participate, 6,976 (35.2 percent) did not reply, and the address information were unavailable for 1,828 (9.2 percent).[841] These figures are almost the same as those of the previous fiscal year.

OFFSITE CHALLENGES

Current Status of Evacuation and Legal Claims

As of 6 April 2020, 38,658 Fukushima residents were still living as evacuees (7,915 are living within the prefecture, 30,730 are living outside the prefecture, and 13 are missing).[842] This number has hardly changed compared to the previous fiscal year. According to Fukushima Prefecture, the peak level of evacuees was 164,865 (May 2012).[843]

Little progress has been made since WNISR2019 in lifting evacuation orders.[844] The only recent lifting of an evacuation order, in March 2020, was for a small part of the remaining Zone in Preparation for Lifting the Evacuation Order.[845][846] In areas where evacuation orders have already been lifted, the number of returnees is still not increasing significantly. For example, the return rate is 1.8 percent in Okuma Town (the location of Fukushima Daiichi Nuclear Power Plant), where the evacuation order was partially lifted in April 2019, and 7.5 percent in Tomioka Town, where the evacuation order was partially lifted in April 2017.[847]

According to the Reconstruction Agency, the earthquake-related deaths[848] caused by the 2011 Great East Japan Earthquake are only prominent in Fukushima Prefecture. As of September 2019, the number of such deaths in Japan was 3,739 of which 2,286 (61 percent of the total) were in Fukushima Prefecture, an increase of 14 deaths from the previous fiscal year.[849]

841 - Radiation Effects Research Foundation, "Comprehensive Research Report of the Epidemiological Study on the TEPCO Fukushima Daiichi Nuclear Power Station Emergency Workers", MHLW, March 2019 (in Japanese), see https://www.news.johas.go.jp/hp/pdf/report_h30.pdf, accessed 4 May 2020.

842 - Fukushima Disaster Measures Headquarters, "Immediate report on damage caused by the 2011 Tohoku Region Pacific Coast Earthquake", Report No. 1764, (in Japanese).

843 - Fukushima prefecture, "Steps for Revitalization Fukushima, December 25, 2018 edition", 25 December 2018, p.3.

844 - The conditions for lifting an evacuation order are: 1. It is certain that the annual accumulated value (estimated value) of air dose rate will be less than 20mSv, 2. Recovery of infrastructure (electricity, gas, etc.) and life services (medical, postal, etc.) essential for daily life. Decontamination of children's living environment and so on will sufficiently progress, 3. Sufficient consultation with prefectures, municipalities and residents. See METI, "Requirements for lifting an evacuation order", December 2011 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/kinkyu/hinanshiji/2017/pdf/0310_01e.pdf, accessed 1 May 2019.

845 - The area where it is certain that annual accumulated value will be less than 20mSv one year after the accident.

846 - METI, "Lifting of evacuation orders in Futaba, Okuma and Tomioka: Conceptual diagram of evacuation zones", Undated (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/kinkyu/hinanshiji/2020/maruni200117gainennzu.pdf, accessed 4 May 2020.

847 - Reconstruction Agency, "Results of the Survey on the Intentions of Residents in the Nuclear Accident-affected Local Municipalities", Summary, 19 March 2020 (in Japanese), see https://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/ikoucyousa/200319_ikouchousa_zentai_gaiyou.pdf, accessed 4 May 2020.

848 - In comparison to deaths due to direct damages caused by the tsunami or earthquake, deaths due to indirect damages (such as poor physical condition or stress) that occur as a result of living as an evacuee following the disaster.

849 - Reconstruction Agency, "Number of deaths of earthquake related death", 27 December 2020 (in Japanese), see https://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-6/20191227_kanrenshi.pdf, accessed 4 May 2020.

TEPCO continues its compensation policy. As of 24 April 2020, the total amount paid out was approximately ¥9.5 trillion (US$95 billion).[850] However, there are still many group complaints against the level of compensation and TEPCO continues to refuse to pay some proposed settlements and consequently the number of lawsuits by residents is increasing. For example, in March 2020, in a lawsuit filed by 216 residents of Fukushima Prefecture seeking compensation, the High Court ordered TEPCO to pay a total of ¥610 million (US$5.6 million)—which was less than was being sought by the claimants but higher than in other court orders.[851]

In September 2019, the Tokyo District Court judge delivered the verdict in the criminal trial of three former TEPCO management members (former chairman and two former vice presidents) accused of professional negligence resulting in injury or death. As a result, the three were acquitted on the grounds that it is unclear whether they could have taken adequate measures even if they could have predicted the tsunami.[852] The ruling was widely condemned as flawed, including its failure to consider the tsunami countermeasure options that TEPCO could have taken prior to 2011, and the lawyers for the plaintiffs have filed an appeal to the Tokyo High Court.[853]

Radiation Exposure and Health Effects

Fukushima Prefecture is still implementing examinations for thyroid cancer for people who were under the age of 18 at the time of the accident.[854] As of February 2020, there were 237 cases of malignancy or suspected malignancy and 187 cases of surgery[855]. These numbers can be compared to the data as of April 2019 with 212 cases of malignancy or suspected malignancy, 169 cases of surgery.[856] Although the numbers of diagnosed cases and of performed operations are increasing every year, the Fukushima Prefectural Health Survey Committee still has not recognized a causal relationship between the occurrence of thyroid cancer and the Fukushima accident. This may not be a sustainable position given emerging evidence of a statistically significant relationship between radiation dose rates and cancer rates. For example, in 2019, a scientific study concluded: "The average radiation dose-rates in the 59 municipalities of the Fukushima prefecture in June2011 and the corresponding thyroid cancer detection rates in the period October 2011 to March 2016 show statistically significant relationships."[857]

850 - TEPCO, "Requests and payments for nuclear damage compensation", as of 24 April 2020 (in Japanese), see http://www.tepco.co.jp/fukushima_hq/compensation/results/, accessed 4 May 2020.

851 - *JIJI Press*, "Increased solatium payment, a 700-million-yen compensation order", 12 March 2020 (in Japanese), see https://www.jiji.com/jc/article?k=2020031201338&g=soc, accessed 4 May 2020.

852 - *BBC*, "Fukushima disaster: Nuclear executives found not guilty", 19 September 2019, see https://www.bbc.com/news/world-asia-49750180, accessed 4 May 2020.

853 - Kaido Yuichi, "TEPCO Criminal Trial: Defendants Acquitted—Court Went Completely Out of its Way to Rescue TEPCO Executives", CNIC, 7 October 2019, see https://cnic.jp/english/?p=4580, accessed 21 July 2020.

854 - Office of International Cooperation, "Radiation Medical Science Center for the Fukushima Health Management Survey".

855 - Fukushima Prefecture, "Status of thyroid examination results", 37th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey, 13 February 2020 (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/369448.pdf, accessed 4 May 2020.

856 - Fukushima Prefecture, "Status of thyroid examination results", 34th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey, 8 April 2019 (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/320844.pdf.

857 - **Hidehiko Yamamoto, Keiji Hayashi and Hagen Scherb, "Association between the detection rate of thyroid cancer and the external radiation dose-rate after the nuclear power plant accidents in Fukushima, Japan", Observational Study,** *Medicine, Vol 98:37(e17165), 2019, see* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6750239/pdf/medi-98-e17165.pdf, accessed 5 August 2020.

Food Contamination

Of 266,424 food samples tested for contamination nationwide in FY2020, 157 food items exceeded the legal limits[858] (FY2019: 313 food items).[859] Among the 29 cases detected in Fukushima Prefecture, 20 cases were detected in wild birds and meats (boar, deer and bear).

Currently, there are still some difficulties for the food export industry. Of the 54 countries that started import restrictions after the Fukushima accident in 2011, as of March 2020, 34 countries have lifted all restrictions, but 20 countries (23 as of April 2019) are still imposing some restrictions.[860] Among the countries suspending food imports from Japan, as of 2019, Hong Kong is the region with the highest export value at ¥203.7 billion (US$2 billion).[861]

Decontamination[862, 863]

Decontamination of the Special Decontamination Area[864] in Fukushima Prefecture directly managed by the Japanese Government was completed in March 2018, and decontamination of designated areas (agricultural fields, along roads, around houses, etc.) in municipalities including the rest of Fukushima Prefecture[865] was completed in March 2017. These programs did not cover difficult-to-return zones and did not cover mountainous forested areas which make up more than 70 percent of Fukushima prefecture.[866]

Meanwhile, the management of the decontamination waste generated by these projects has turned into a major issue. The contaminated soil in the temporary storage area in Fukushima Prefecture is currently being transferred to intermediate storage facilities[867] in eight areas. As of June 2020, the total amount transferred was 7.81 million m^3 out of a total of 14 million m^3. Thus, around 56 percent of the total has been shipped.[868, 869] The sorting and storage activities

858 - 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.

859 - MHLW, "Public inspection result FY 2019—outline (preliminary value)", as of 30 March 2020 (in Japanese).

860 - Food Industry Affairs Bureau, "Status of countries and regions introduced import measures on Japanese foods after the TEPCO's Fukushima Daiichi Nuclear Power Plant accident", Ministry of Agriculture, Forestry and Fisheries, as of 2 March 2020, see https://www.maff.go.jp/j/export/e_info/pdf/kisei_gaiyo_en.pdf.

861 - Ministry of Agriculture, Forestry and Fisheries, "Elimination and relaxation of food and other food import restrictions in foreign countries and regions due to the nuclear accident", as of 16 January 2020 (in Japanese), see https://www.maff.go.jp/j/export/e_info/pdf/teishi.pdf.

862 - Ministry of the Environment, "Environmental Remediation", Undated, see http://josen.env.go.jp/en/, accessed 30 July 2020.

863 - Ministry of the Environment, "Off-site Environmental Remediation in Affected Areas in Japan", March 2020, see http://josen.env.go.jp/en/pdf/environmental_remediation_2003.pdf, accessed 4 May 2020.

864 - A high dose area within a 20 km radius of the power plant, located around the difficult-to-return zone.

865 - It covers all eight prefectures, including Fukushima Prefecture, except for the Special Decontamination Area managed by the government.

866 - It is considered as an area where residence will be restricted well into the future. However, decontamination work to enable residence is currently being carried out in some areas (Specified Restoration and Revitalization Base).

867 - Until final disposal, facilities store removed soil, waste, incinerated ash with levels exceeding 100,000 Bq/kg, etc. that were generated from decontamination activities in Fukushima Prefecture.

868 - Ministry of the Environment, "Off-site Environmental Remediation in Affected Areas in Japan", 16 July 2020, see http://josen.env.go.jp/en/pdf/environmental_remediation_2007.pdf, accessed 30 July 2020.

869 - With the volume of one flexible container bag being about 1 m^3, there are 14 million bags.

have already started (see Figure 45).[870] Picture 1 shows one of Okuma area's receiving and sorting facilities. Black flexible container bags can be seen at the bottom of the photo. Picture 2 shows a soil storage facility which is vast but has a storage capacity of only about 180,000 m³. After 30 years of intermediate storage, the decontaminated soil is planned for final disposal outside Fukushima Prefecture, but its location has not yet been determined.

Figure 45 · Receiving and Sorting Facility (Left) and Soil Storage Facility (Right), Okuma Town, Fukushima Prefecture

Source: Ministry of the Environment, 2020

Contaminated soil containing 8,000 Bq/kg or more[871] in prefectures other than Fukushima Prefecture must be kept as is by the respective administration. According to a calculation by the Ministry of the Environment, for example, the 3,643 tons of contaminated soil in Ibaraki Prefecture should decrease to just 0.6 tons (no typo) after processing.[872] Firstly, cesium is separated from contaminated soil by chemical treatment or heat treatment and recovered with an adsorbent. After volume reduction, it will be stored in an intermediate storage facility for 30 years. Finally, the soil will be transported to the final disposal site located outside the prefecture. However, volume reduction technology is still in the stage of verification and testing.[873]

However, the remaining amount of the 135,333 tons of contaminated soil in Tochigi Prefecture will still be 4,250 tons 15 years later.[874]

870 - Ministry of the Environment, "The situation of the intermediate storage facility project", August 2019 (in Japanese), see http://josen.env.go.jp/chukanchozou/action/safety_commission/pdf/safety_commission_02_190828.pdf, accessed 4 May 2020.

871 - According to the Ministry of the Environment, if the level of contamination in the soil is 8,000 Bq/kg, the workers' exposure dose when landfilling the incinerated ash will be lower than the dose limit of 1 mSv/year for public exposure recommended by the ICRP (when working 1,000 hours per year––8 hours a day, 50 percent of 250 days per year working time––near incineration ash).

872 - We are not aware of any independent assessment of these spectacular volume reduction targets.

873 - JESCO, "Technology demonstration projects such as volume reduction of removed soil", Japan Environmental Storage & Safety Corporation, Undated (in Japanese), see http://www.jesconet.co.jp/interim/information/josenjissho.html.

874 - Ministry of the Environment, "Estimation of future radioactivity concentrations of designated wastes in 5 prefectures", Undated (in Japanese), see http://shiteihaiki.env.go.jp/initiatives_other/others_materials/pdf/others_materials_info_1602.pdf, accessed 4 May 2020.

CONCLUSION

Approaching ten years after 3/11, as of 1 July 2020, the work at Fukushima Daiichi remains in the preparatory phase of decommissioning. That is critically important, essential, but it should not be confused with actual decommissioning. The actual "decommissioning work" usually starts after the removal of spent fuel. According to that definition, decommissioning has not even begun, as spent fuel is still stored in three of the four reactor pools.

Furthermore, "evacuation" usually refers to removing people temporarily from a specific location in order to avoid danger. According to that definition, the current situation of tens of thousands of "evacuees" who have been deprived of a normal life for nearly ten years and for many who will never return home is rather to be called near-permanent displacement. But they remain under the status of evacuees. The Government's policy of pressurized return to contaminated areas is failing and has no prospect of success. The consequences of the on-going nuclear disaster at Fukushima remain complex and serious.

DECOMMISSIONING STATUS REPORT 2020

INTRODUCTION AND OVERVIEW

Decommissioning Worldwide

Decommissioning nuclear power plants is an important element of the nuclear power system, and one that remains under-researched. The defueling, deconstruction, and dismantling—summarized by the term decommissioning—are the final steps in the life cycle of a nuclear power plant (excluding waste management and disposal). The process is technically complex and poses major challenges in terms of long-term planning, 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 discounted away, and thus, subsequently, largely ignored. However, as an increasing number of nuclear facilities either reach the end of their operational lifetimes or are already closed, the challenges of reactor decommissioning are coming to the fore, and also attract increasing public attention.

As of 1 July 2020, worldwide, there are 189 closed reactors totaling 84 GW of capacity. Since WNISR2019, eight additional reactors (6.3 GW) have officially been closed: two in the U.S. (Indian Point-2 and Three Mile Island-1), two in France (Fessenheim-1 and -2), one each in Germany (Philippsburg-2), Sweden (Ringhals-2), Switzerland (Mühleberg) and Taiwan (Chinshan-2). Of the closed units, 60 percent are located in Europe (90 in Western Europe and 23 in Central and Eastern Europe), with nearly a quarter of closed units in North America (44) and one sixth in Asia (32). Almost four in five or 148 reactors used three technologies: Pressurized Water Reactors (PWRs) (32 percent or 60 units), Boiling Water Reactors (BWRs) (27 percent or 50 units), and Gas-Cooled Reactors (GCRs) (20 percent or 38 units). Of the latter, the majority (27 units) are in the U.K.

Decommissioning plays an increasing role in nuclear politics, both in timing and production process, and therefore financing. The number of reactors facing decommissioning will increase significantly over the coming decade: assuming a 40-year average lifetime, a further 203 reactors will close by 2031 (reactors connected to the grid between 1980 and 1991); and an additional 122 will be closed by 2060; this does not even account for the 83 reactors which started operating before 1980, an additional 31 reactors in Long-term Outage (LTO) and the 52 reactors under construction as of mid-2020.

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 decommissioning. The International Atomic Energy Agency (IAEA) defines decommissioning as the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility.[875] The technical actions of the decommissioning process 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, the dismantling of systems that are not needed for the decommissioning process. Also, the dismantling of higher contaminated system parts begins. A key 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 the Reactor Vessel Internals (RVI), the biological shield.
- The **ease-off stage** comprises the removal of operating systems as well as decontamination of the buildings. This stage ideally ends with the demolition of the buildings and site remediation to the state of a greenfield. The completion of this stage defines the end of the technical decommissioning process.

Once the technical process is completed, final site survey and the necessary administrative steps for the removal of the regulatory control of the facility are carried out. Depending on the national regulatory framework, the site can be released as a greenfield or brownfield. Brownfield use is allowed in some countries, which means that the buildings can continue to be used for nuclear and other purposes. The license can also be reduced; this is the case in the U.S., where the license is reduced to only covering the remaining spent fuel storage installations. 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).

Overview of Reactors with Completed Decommissioning

As of the first quarter of 2020, 169 units are globally awaiting or in various stages of decommissioning, seven more than in the first quarter of 2019. Since WNISR2019, one reactor finished the technical decommissioning process. In November 2019, EnergySolutions announced the completion of the "physical work" at the La Crosse station.[876] Final site survey and license reduction to the independent spent fuel installation is currently planned for 2020.[877] The 48-MW La Crosse plant was decommissioned 37 years after its closure. This finished decommissioning project increased the total number of decommissioned reactors from 19 to 20, with a total capacity of around 6 GW. This represents only 7 percent of the total 85 GW withdrawn from the grid.

Of the 20 decommissioned reactors, only 10 have been returned to greenfield sites. The average duration of the decommissioning process, independent of the chosen strategy, is around 20 years, with a very high variance: the minimum of six years for the 22-MW Elk River plant,

875 - IAEA, "IAEA Safety Glossary—Terminology Used in Nuclear Safety and Radiation Protection", International Atomic Energy Agency, June 2007, see http://www-pub.iaea.org/MTCD/publications/PDF/Pub1290_web.pdf, accessed 7 July 2020.

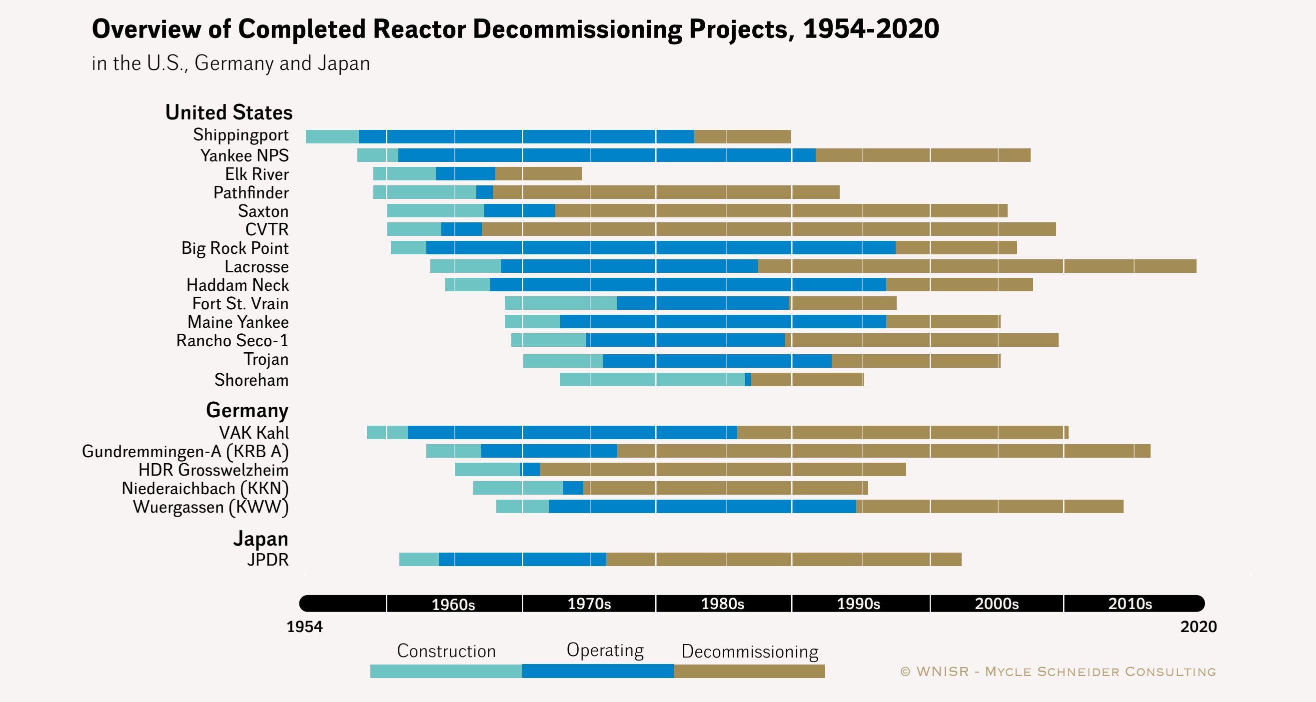
876 - *NEI Magazine*, "Physical work completed for decommissioning of US La Crosse NPP", 14 November 2019, see https://www.neimagazine.com/news/newsphysical-work-completed-for-decommissioning-of-us-la-crosse-npp-7508092, accessed 7 July 2020.

877 - NRC, "La Crosse Boiling Water Reactor", Updated 19 November 2019, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/lacrosse-boiling-water-reactor.html, accessed 7 July 2020.

and the maximum of 42 years for the 17-MW CVTR (Carolinas-Virginia Tube Reactor), both in the U.S.

The only countries to have completed the technical decommissioning process are the United States (14), Germany (5), 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. Gundremmingen-A and Würgassen have de facto completed the technical decommissioning process but, legally, cannot be released from regulatory control as buildings are used for interim storage of wastes or conditioning work for operational units (in the case of Gundremmingen).[878] In Japan, the only reactor decommissioned was a small research reactor, whereas none of the commercial reactors has yet been decommissioned.[879] Figure 46 provides the timelines of the 20 reactors that have completed the decommissioning process.

Figure 46 · Overview of Completed Reactor Decommissioning Projects, 1953–2020



Sources: Various, compiled by WNISR, 2020

Notes:

CVTR: Carolinas-Virginia Tube Reactor; HDR: Heißdampfreaktor/Boiling Water Reactor; KKN: Kernkraftwerk/Nuclear Power Station Niederaichbach; KWW: Kernkraftwerk/Nuclear Power Station Würgassen; JPDR: Japan Power Demonstration Reactor.

878 - Ines Bredberg et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2018", Bundesamt für kerntechnische Entsorgungssicherheit, 2019.

879 - 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-japan-schmittem-min_0.pdf, accessed 23 April 2018.

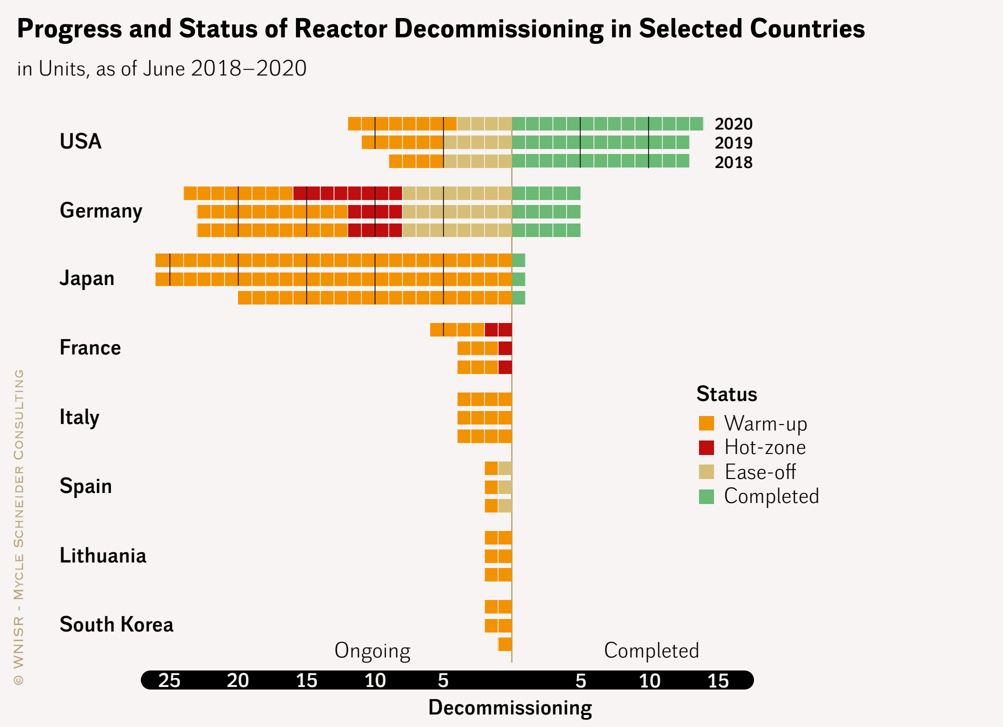
OVERVIEW OF REACTORS WITH ONGOING DECOMMISSIONING IN 11 SELECTED COUNTRIES

WNISR2018 provided an in-depth review of developments in six major countries, namely in the U.S., Canada, France, Germany, Japan, and the U.K. covering 136 closed reactors. WNISR2019 updated these case studies and provided an in-depth review of developments in Spain, Italy, Lithuania, Russia, and South Korea. Altogether, WNSIR2019 covered a total of 159 closed reactors, representing almost 87 percent of the worldwide closed fleet. The country case-studies suggest that both duration and costs have been largely underestimated. In nearly all the cases, the ongoing decommissioning projects encounter delays as well as cost increases.

WNISR2020 provides an update of these case studies. This section provides a review of developments since WNISR2019, while the following section contains the more detailed case studies. WNISR2020 counted 164 reactors currently in the different decommissioning stages in these 11 countries; this represents around 87 percent of all closed reactors.

Currently 55 are in the warm-up stage, only 10 reactors in the "hot-zone -stage", and 13 are in the ease-off stage. The early nuclear states U.K., France, Russia, and Canada have not fully decommissioned one single reactor. Canada, U.K. and Russia put all their closed reactors into Long-Term Enclosure (LTE), postponing decommissioning into the future. The U.S. has also a large number of reactors in LTE too. WNISR2020 counts a total of 66 reactors in LTE in these 11 countries, one third of all closed units.

Figure 47 · Progress and Status of Reactor Decommissioning



Sources: Various, compiled by WNISR, 2018–2020

Note: This graph does not include 22 reactors in LTE (long-term enclosure) in four of those countries, including twelve in the U.S., eight in France, and one each in Germany and Spain.

Figure 47 reflects the little progress that the global decommissioning industry is making. Between July 2019 and June 2020, little progress can be reported for most of the reactors undergoing decommissioning except for the U.S. In France, the two Fessenheim reactors entered the warm-up stage and Superphénix entered the hot-zone stage. In Germany four reactors advanced to the hot-zone stage, while one additional reactor entered the warm-up-stage. In the U.S., two more reactors entered the warm-up stage, while one plant finished the technical decommissioning process (see the following Case Studies for details).

Focus Country: United States

The U.S. has not only the largest fleet of operating (95) and closed reactors (38), but also the highest number of decommissioned units (14) in the world, representing about two thirds of the total. WNISR2020 therefore looks in detail into the decommissioning sector in the U.S.

Decommissioning Monitoring

In the U.S., so far, 38 reactors (17.5 GW) have been closed.[880] By 2050, at least 100 reactors are likely to be undergoing decommissioning in the country. Of the 38 reactors (19 PWR, 13 BWR, 2 HTGR, 1 FBR, 1 PHWR, 2 others)[881], 14 units or 5 GW have been decommissioned (see Table 12). Currently, decommissioning work is ongoing at 12 units:

- Eight reactors are in the warm-up stage: Fort Calhoun-1, Vermont Yankee, San Onofre-2 and -3, Oyster Creek, Pilgrim, Indian Point-2, and Crystal River-3;
- Four reactors are in ease-off stage (Humboldt Bay, San Onofre-1, Zion-1 and -2).

Since WNISR2018, the number of reactors in the warm-up stage has doubled to eight reactors in 2020, although no unit has yet entered the hot-zone stage. In May 2020, the operator Omaha Public Power District (OPPD) announced that Fort Calhoun-1 (482 MW) was defueled, with fuel being stored in dry casks.[882] Crystal River-3[883] and Vermont Yankee[884] are defueled too. San Onofre-2 and -3[885] were scheduled to be defueled by 2019, but that goal was not achieved[886]. Since

880 - 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. NRC, "Status of the Decommissioning Program—Annual Report", 2018.

881 - PWR: Pressurized Water Reactor; BWR: Boiling Water Reactor; HTGR: High-Temperature Gas-Cooled Reactor; FBR: Fast Breeder Reactor; PHWR: Pressurized Heavy-Water Reactor.

882 - *The Wire*, "Video: Fort Calhoun Station crosses fuel-move milestone", *Omaha Public Power District*, 18 May 2020, see https://oppdthewire.com/nuclear-decommissioning-spent-fuel-secure-2020/, accessed 7 July 2020.

883 - NRC, "Crystal River Unit 3 Nuclear Generating Plant", 2019, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/cr3.html, accessed 11 May 2020.

884 - William Irwin, "Experiences with the Decommissioning of Vermont Yankee", Radiological & Toxicological Sciences Program, Vermont Department of Health, presented at the NDCAP Meeting, 24 January 2018, see https://www.mass.gov/files/documents/2018/01/25/bill-irwin-1-24-2-18-mass-ndcap-presentation.pdf, accessed 1 June 2018.

885 - In 2014, former CEO of San Onofre majority owner Southern California Edison and then California Public Utilities Commission (CPUC) President Michael Peevey approved a deal that put 70 percent of the estimated US$4.7 billion "early closure" costs for both units onto the shoulders of the ratepayers. Then in February 2018, a settlement was reached that will see the utilities cover US$775 million in final costs for the closure of the power plant, overriding the 2014 agreement.
See Jeff St. John, "Southern California Utilities to Pay $775M in San Onofre Closure Deal", *GreenTech Media*, 1 February 2018, see https://www.greentechmedia.com/articles/read/southern-california-utilities-to-pay-775-in-final-san-onofre, accessed 5 July 2018.

886 - Southern California Edison, "Decommissioning Funding Status Report San Onofre Nuclear Generating Station Units 1, 2, and 3 and ISFSI", addressed to the U.S.NRC, 10 CFR 50.75, 10 CFR 50.82 and 10 CFR 72.30, 28 March 2017, see https://www.nrc.gov/docs/ML1709/ML17090A152.pdf, accessed 7 September 2020.

WNISR2019, two more reactors went permanently offline: the 45-year old Three Mile Island-1 in Pennsylvania was closed in September 2019, and the 47-year old Indian Point-2 in New York followed in April 2020. Exelon, the operator of Three Mile Island-1, closed the station 15 years ahead of the expiration of the operating license due to unfavorable economic conditions. Exelon plans to completely defuel the pools by 2022 and opts for the LTE strategy[887]. Total decommissioning is estimated to take 60 years for a total cost of US$1.2 billion[888] around US$1,465/kW. Holtec and Entergy agreed on the transfer of the three Indian Point reactors (Unit 1 is in LTE, Unit 3 is scheduled to close in 2021) to a Holtec International subsidiary for immediate decommissioning. The decommissioning strategy for Crystal River-3 was changed from LTE to immediate decommissioning after the NorthStar-Orano joint-venture purchased the unit. WNISR2020 counts the reactor now, with the approval of the Nuclear Regulatory Commission (NRC), as in the warm-up-stage.

Since WNISR2019, La Crosse de facto finished technical decommissioning, 32 years after closure. However, the site is not yet released from regulatory control as the final site survey and license reduction to the independent spent fuel installations on site are still pending.

For the decommissioned reactors, the process was completed on average 17 years after the closure of the reactor. In six cases, decommissioning was completed in less than 10 years, which is quick by international comparison. One reason for these short decommissioning periods is that in most cases the pressure vessel was removed and transported intact for final disposal, while the internals were segmented under water or in air and dry stored onsite along with spent nuclear fuel awaiting a federal repository.[889]

Among the shortest of all decommissioning periods is Shippingport, where decommissioning took only seven years. In this case, not only the reactor pressure vessel was removed as a whole, but also the vessel internals were not segmented but put into the vessel and disposed of at a disposal site together, using the vessel as shipping container.[890] In some cases, this removal as a whole was also done for other larger components, e.g. the steam generators. This not only led to short decommissioning times but also lower costs ranging from US$280/kW (Trojan plant, Oregon) to US$1,500/kW (Haddam Neck, Connecticut).[891]

The U.S. has also a large number of reactors in LTE (12 units or 3.6 GW, including three units in "Entombment"[892]). The LTE period is limited to 60 years, after which the reactor has to

887 - Exelon, "Three Mile Island Decommissioning", Undated, see https://www.exeloncorp.com/locations/three-mile-island-decommissioning, accessed 11 May 2020.

888 - Andrew Maykuth, "Three Mile Island's 60-year shutdown: 'More akin to a marathon than a sprint'", *The Philadelphia Inquirer*, 16 July 2019, see https://www.inquirer.com/business/three-mile-island-nrc-nuclear-decommissioning-plans-spelled-out-20190716.html, accessed 11 May 2020.

889 - T. S. LaGuardia, "Decommissioning of Western-type light-water nuclear reactors (LWRs)", in "Nuclear Decommissioning—Planning, Execution and International Experience", *Woodhead Publishing Series in Energy*, 2012, pp. 513–563, see https://www.sciencedirect.com/science/article/pii/B9780857091154500191, accessed 2 May 2018.

890 - Karen Dorn Steele, "Hanford: America's Nuclear Graveyard", *Bulletin of the Atomic Scientists*, 1 October 1989.

891 - The total costs including the site restoration amounted to US$836 million for Connecticut Yankee (also named Haddam Neck), see OECD/NEA, "Costs of Decommissioning Nuclear Power Plants", Nuclear Energy Agency / Organisation for Economic Co-operation and Development, 2016.

892 - Entombment is defined by the NRC as "A method of decommissioning, in which radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombed structure is maintained and surveillance is continued until the entombed radioactive waste decays to a level permitting termination of the license and unrestricted release of the property". For further information, see U.S.NRC, "Glossary", Updated 29 June 2020, see https://www.nrc.gov/reading-rm/basic-ref/glossary/entomb.html, accessed 7 September 2020.

be decommissioned. Problems of knowledge management, availability of human and financial resources in the decades to come, and safety issues during LTE still have to be resolved.

Finally, as in other countries exploring decommissioning, one of the largest hurdles is the disposal of used nuclear fuel and "Greater-Than-Class C" or GTCC waste[893], as facilities continue to host waste onsite preventing full regulatory release as a greenfield site.[894] In these cases, the site license is reduced to the Independent Spent Fuel Storage Installation (ISFSI): a dry storage facility for spent fuel installed on the site. Of the fully decommissioned reactors, more than half (8) of the sites have been or will be relicensed as ISFSI. With no centralized interim storage facility and no disposal solution for spent fuel, ISFSIs will likely spread in the future. Table 12 shows the current status of reactor decommissioning in the U.S.

Table 12 · Status of Reactor Decommissioning in the U.S. (as of May 2020)

United States of America	May 2018	May 2019	May 2020
"Warm-up-stage"	4	6	8
of which defueled	*1*	*1*	*3*
"Hot-zone-stage"	0	0	0
"Ease-off-stage"	5	5	4
LTE	12[(a)]	12[(a)]	12[(a)]
Completed	13	13	14
of which released from regulatory control	*6*	*6*	*6*
Total Closed Reactors	**34**	**36**	**38**

Sources: Various, compiled by WNISR, 2020

Notes:

LTE: Long-Term Enclosure.

a - Of which 3 reactors are in "Entombment": the Department of Energy-reactors Piqua (Ohio), Bonus (Puerto Rico), Hallam (Nebraska).

Organizational Challenges

Decommissioning Funds Under Threat

Going forward, decommissioning in the U.S. faces challenges of effective dismantling and of financing the process in a context of low electricity prices placing a further strain on the competitiveness of nuclear power plants, early closures, and low provisions of earmarked funds.[895] Approximately 70 percent of the owners of nuclear power plants in the U.S.—generally traditional, rate-regulated utilities—collect decommissioning money from customers' reactor-specific payments in Nuclear Decommissioning Trust funds (NDT), while the remaining operators must provide financial assurance through one of the other two basic methods (a

893 - For further information on GTCC and waste classification in the U.S., see U.S.NRC, "Greater-Than-Class-C and Transuranic Waste", Updated 9 October 2019, see https://www.nrc.gov/waste/llw-disposal/llw-pa/gtcc-transuranic-waste-disposal.html, accessed 7 September 2020.

894 - Robert Rosner and Rebecca Lordan, "Why America should move towards dry cask consolidated interim storage of used nuclear fuel", *Bulletin of the Atomic Scientists*, 2014.

895 - Ben Wealer et al., "Nuclear Energy Policy in the United States: Between Rocks and Hard Places", IAEE Energy Forum, 2017.

prepayment; a surety, insurance, or parent-company guarantee).[896] In 2016, the overall balance in the NDT as around US$64 billion, with specific costs to decommission a nuclear reactor of around US$700/kW for public power utilities and US$850/kW for investor-owned utilities.[897]

There is an increasing risk that the NDT will not be sufficient to cover all the decommissioning costs in the foreseeable future due to systematic underestimation of future costs and a significant number of early closures. Especially important is the fact that an increasing number of nuclear plants are taken off the grid for good due to deteriorating economic conditions, leading to lower income, as in most cases the NDT is built up year-by-year over the expected lifetime of the reactor. A recent audit by the U.S. Office of the Inspector General concluded that the cost estimates should be based on the best available knowledge from research and operational experience, but with the Nuclear Regulatory Commission (NRC) estimation formula being based on studies conducted between 1978 and 1980, this is hardly fulfilling the conditions. The audit recommended among other things that the funding formula be re-evaluated to determine whether a site-specific cost estimate would be more efficient.[898]

Outsourcing the Decommissioning Process: EnergySolutions, NorthStar, Holtec International

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.[899] 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. 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.

EnergySolutions, the major waste management service provider, which seems to be involved in nearly all decommissioning projects and also provided support for early nuclear power plant decommissioning projects, including those at Fort St. Vrain, Trojan, Haddam Neck, Maine Yankee and Yankee Rowe[900] was the first company to acquire units for decommissioning through limited liability subsidiaries. This was done for the first time for the two Zion units in Illinois and La Crosse in Wisconsin.

In 2019, EnergySolutions, for the first time, announced that it completed a decommissioning project, at least from a technical point-of-view, as final site survey of the La Crosse site and license

896 - Julia A. Moriarty, "2017 Nuclear Decommissioning Funding Study", Callan Institute, 2017, see https://www.callan.com/wp-content/uploads/2017/09/Callan-2017-NDT-Survey.pdf.

897 - Ibidem.

898 - Office of the Inspector General, "Audit of NRC's Decommissioning Funds Program", United States Nuclear Regulatory Commission, Defense Nuclear Facilities Safety Board, June 2016, see https://www.nrc.gov/docs/ML1616/ML16160A208.pdf, accessed 1 May 2018.

899 - Conrad Cooke and Holger Spann, "Reactor vessel internals segmentation at Zion", *Nuclear Engineering International*, 20 September 2013, see http://www.neimagazine.com/features/featurereactor-vessel-internals-segmentation-at-zion/; and AREVA, "Decommissioning & Dismantling", AREVA, 2018, see http://us.areva.com/EN/home-3783/orano-usa-decommissioning--dismantling.html.

900 - *WNN*, "EnergySolutions to decommission Fort Calhoun", 3 April 2019, see http://world-nuclear-news.org/Articles/EnergySolutions-to-decommission-Fort-Calhoun, accessed 9 May 2019.

reduction to the ISFSI is currently planned for 2020. The ISFSI will then again be transferred to Dairyland Power Cooperative. The infamous second unit of Three Mile Island (TMI) is owned by GPU Nuclear, a subsidiary of FirstEnergy (which filed for bankruptcy in 2018). EnergySolutions negotiated with GPU Nuclear on purchasing TMI-2, currently in LTE, and to complete its decommissioning. With the basic terms agreed, EnergySolutions and FirstEnergy will proceed with definitive agreements and applications to the NRC for the transfer of all licenses and assets.[901] The contract between EnergySolutions and the FirstEnergy subsidiary was signed in October 2019 and the decommissioning responsibility will be transferred to EnergySolutions subsidiary TMI-2 Solutions LLC. To perform the decommissioning work at TMI-2, EnergySolutions and New Jersey-based construction company Jingoli formed a joint venture, called ES/Jingoli Decommissioning LLC.[902]

Another company entering the decommissioning market is U.S. company **NorthStar**, which so far is lacking major decommissioning experience. NorthStar had entered into a purchase-and-sale agreement with Entergy for Vermont Yankee; the deal included the transfer of the decommissioning trust and, in 2017, Entergy promised to add another US$125 million. NorthStar had already signed a contract with AREVA (now Orano) for the dismantling of the pressure vessel and internal structures.[903] The State of Vermont petitioned before the Atomic Safety and Licensing Board of the NRC for leave to intervene in the plans and hearing request due to underestimated risks to the ratepayers.[904] Then in December 2018, the Vermont Public Utility Commission approved the license transfer to NorthStar, in particular due to the accelerated decommissioning plan, NorthStar would start with decommissioning no later than 2021.[905] The transfer includes the dry storage facility[906] but questions remain on the secure funding.

In June 2019, the owner of Crystal River-3, Duke Energy, announced that it plans to sell the operating license for Crystal River-3, which is currently in LTE, to the NorthStar and Orano joint-venture Accelerated Decommissioning Partners.[907] The US$540 million-deal would foresee decommissioning the station by 2027, around 50 years earlier and US$260 million cheaper.[908] In April 2020, the NRC approved the transfer. Under this agreement Duke Energy will remain the owner of the reactor and retain ownership and control of the decommissioning

901 - Rod Walton, "EnergySolutions signs deal on final decommissioning efforts for Three Mile Island Unit 2", *Power Engineering*, 24 July 2019, see https://www.power-eng.com/2019/07/24/energysolutions-signs-deal-on-final-decommissioning-efforts-for-three-mile-island-unit-2/#gref, accessed 11 May 2020.

902 - *WNN*, "EnergySolutions adds TMI-2 to decommissioning projects", 16 October 2019, see https://www.world-nuclear-news.org/Articles/EnergySolutions-takes-on-TMI-2-for-decommissioning, accessed 11 May 2020.

903 - Timothy McQuiston, "French firm wins Vermont Yankee reactor dismantling contract", *Vermont Business Magazine*, 12 July 2017, see https://vermontbiz.com/news/july/french-firm-wins-vermont-yankee-reactor-dismantling-contract, accessed 2 May 2018.

904 - U.S. NRC, "State of Vermont's petition for leave to intervene and hearing request", 2017, see https://www.nrc.gov/docs/ML1716/ML17164A419.pdf, accessed 3 July 2018.

905 - John Dillon, "Vermont Yankee transfer approved, Northstar will decommission plant", *Vermont Public Radio*, 7 December 2018, see https://www.nepm.org/post/vermont-yankee-transfer-approved-northstar-will-decommission-plant, accessed7 September 2020.

906 - U.S.NRC, "NRC Approves License Transfer for Vermont Yankee", Press Release No. 18-047, 12 October 2018, see https://www.nrc.gov/reading-rm/doc-collections/news/2018/18-047.pdf, accessed 16 August 2020.

907 - *WNN*, "Accelerated decommissioning for Crystal River", 31 May 2019, see http://www.world-nuclear-news.org/Articles/Accelerated-decommissioning-for-Crystal-River, accessed 1 June 2019.

908 - *Nuclear Energy Insider*, "Crystal River to be decommissioned 50 years early", *Reuters*, 5 June 2019, see https://analysis.nuclearenergyinsider.com/crystal-river-be-decommissioned-50-years-early, accessed 11 May 2020.

fund; while Accelerated Decommissioning Partners will become the NRC licensee responsible for decommissioning the station.

A third company following EnergySolutions and NorthStar is **Holtec International**. The company is already involved in numerous decommissioning projects through their dry cask storage and transportation products but not yet in large-scale decommissioning projects. According to Holtec, the company purchases the reactors with the objective to move quickly, transfer the reactors' used fuel into dry storage and ultimately to a "consolidated interim storage" facility that Holtec seeks to build in southeast New Mexico.[909]

In mid-2019, the NRC approved of the transfer of the operating license of Oyster Creek from Exelon to Holtec subsidiaries Oyster Creek Environmental Protection LLC (OCEP) as owner, and Holtec Decommissioning International, LLC (HDI) as operator for decommissioning.[910]

In August 2019, Pilgrim Nuclear Power Station was purchased by Holtec International in a deal that allowed the site to enter immediate decommissioning.[911] Holtec Pilgrim LLC will own the company; HDI is the licensed operator.[912] The NRC approved the deal. Holtec and Entergy also agreed on the transfer of the three Indian Point reactors (Unit 1 is in LTE, Unit 3 is still operating but scheduled to close in 2021) to a Holtec International subsidiary for immediate decommissioning; the license transfer application is currently reviewed by the NRC.[913] Holtec has proposed decommissioning and demolishing the facility by year-end 2033, at a projected cost of US$2.3 billion.[914]

Of the 12 reactors currently in the warm-up and ease-off stage as well as recently completed La Crosse, only Humboldt Bay was not transferred to a decommissioning licensee or contracted to one of the above companies. Already seven units were transferred to decommissioning companies, while another two transfers are pending for two units which are slated for decommissioning in the coming years. Table 13 gives an overview of the outsourcing of the decommissioning process to these three companies. Overall, the new scheme of outsourcing entire decommissioning steps may have an advantage of generating economies of scale. In fact, a specialized company (e.g. Energy Solutions) may be able to benefit from a large number of reactors that it decommissions. The new organizational model also seems to accelerate decommissioning at a first glance. The two units TMI-2, Indian Point-1, which are currently in LTE (for 60 years) could enter the decommissioning process in the coming years. On the other

909 - Joy Russel, "Holtec: Oyster Creek nuke site offer explained", Chief Communications Officer, Holtec International, Letter published in *South Jersey Times*, 12 August 2019, see https://www.nj.com/opinion/2018/08/holtec_oyster_creek_nuke_site_offer_explained_feedback.html, accessed 11 May 2020.

910 - Holtec International, "Holtec Completes Acquisition of Oyster Creek Generating Station", 1 July 2019, see https://holtecinternational.com/2019/07/01/holtec-completes-acquisition-of-oyster-creek-generating-station/, accessed 11 May 2020.

911 - Holtec Decommissioning International, "Pilgrim Nuclear Power Station Decommissioning", n.d., see https://hdi-decom.com/our-fleet/pilgrim-decommissioning/, accessed 11 May 2020.

912 - Holtec Decommissioning International, LLC (HDI) will contract out the work through a Decommissioning General Contractor Agreement to Comprehensive Decommissioning International, which is jointly owned by Holtec (through its subsidiary Holtec Decommissioning International, majority holder) and SNC-Lavalin (through its subsidiary Kentz, USA). Entergy, "Application for Order Consenting to Direct and Indirect Transfers of Control of Licenses and Approving Conforming License Amendment; and Request for Exemption from 10 CFR 50.82(a)(8)(i)(A", 16 November 2018, Docket Nos. 50-293 & 72-1044, see https://hdi-decom.com/wp-content/uploads/2019/08/Pilgrim-License-Transfer-Application-Without-Enclosure-1P.pdf.

913 - Allison Dunne, "NRC Delivers Briefing On Indian Point Decommissioning", *WAMC Northeast Public Radio*, 22 April 2020, see https://www.wamc.org/post/nrc-delivers-briefing-indian-point-decommissioning, accessed 16 September 2020.

914 - Darrell Proctor, "Indian Point Unit 2 Will Shut Down April 30", *POWER Magazine*, 27 April 2020, see https://www.powermag.com/indian-point-unit-2-will-shut-down-april-30/, accessed 11 May 2020.

hand, the success of this model relies on the contract design and the appropriate allocation of risks. A major concern is the allocation of the financial risk of cost overruns. In fact, if the decommissioning funds are exhausted, such a third-party company could declare bankruptcy, leaving the bill for the taxpayer.[915]

Table 13 · Overview of Outsourcing of U.S. Decommissioning Projects

Company	License Transfers	General Decommissioning Contractor (without license transfer)
EnergySolutions	**4 units:** Zion-1, Zion-2, Lacrosse, Three Mile Island-2 (pending)	Fort Calhoun-1, San Onofre-1, San Onofre-2, San Onofre-3
Accelerated Decommissioning Partners (NorthStar-Orano joint-venture)	**2 units:** Vermont Yankee, Crystal River-3	
Holtec (wit SNC-Lavalin)	**6 units:** Oyster Creek, Pilgrim, Indian Point-1 (in LTE, pending), Indian Point-2 (pending), Indian Point-3 (pending), Palisades (operational)	
Total	**12 units**	**4 units**

Sources: Various, compiled by WNISR, 2020

However, according to some NGOs, closer scrutiny of these companies raises some serious concerns, for instance SNC-Lavalin faces a big bribery scandal at home, in Canada, and corruption allegations also in Mexico, India and Bangladesh; therefore close attention should to be paid on money flows and radioactive waste stream.[916]

COUNTRY CASE STUDIES

Canada

In Canada, no commercial reactor has been decommissioned thus far. By mid-2020, six reactors or 2.1 GW, all CANDU—CANadian Deuterium Uranium—reactors except for Gentilly-1, a Heavy-Water Moderated Boiling Light-Water Cooled Reactor (HWBLWR) had been closed. Although some parts have been dismantled of the closed facilities, not one CANDU reactor has even started decommissioning. Gentilly-1, the demonstration reactor in Rolphton, as well as the Douglas Point station are now licensed as waste facilities.[917] In 2016, decommissioning licenses were issued for Gentilly-2 as well as for Pickering-1 and -2. The Pickering units last generated electricity in 1997 but were officially closed only in 2007–2008 and are also in Long-Term Enclosure (LTE).[918] The financial burden of decommissioning is to be shouldered by the operators Ontario Power Generation (OPG), Bruce Power, and New Brunswick Power. However, OPG and New Brunswick Power are wholly-owned public companies.

915 - D. Schlissel, P. Peterson and B. Biewald, "Financial Insecurity: The Increasing Use of Limited Liability Companies and Multi-Tiered Holding Companies to Own Nuclear Power Plants", Synapse Energy Economics; STAR Foundation Riverkeeper, Inc., 2002.

916 - Beyond Nuclear, "Company to decommission US reactors has corruption history", 5 August 2018, see http://www.beyondnuclear.org/home/2018/8/5/company-to-decommission-us-reactors-has-corruption-history.html, accessed 11 May 2020.

917 - CNSC, "Nuclear Power Plants—Decommissioning activities", 28 October 2016, see https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/index.cfm#DA, accessed 2 May 2018.

918 - CNSC, "Gentilly-2 Nuclear Facility", Canadian Nuclear Safety Commission, September 2017, see http://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/gentilly-2-nuclear-generating-station/index.cfm, accessed 2 May 2018.

The required decommissioning fund is accumulated by making annual contributions over the entire planned lifetime of the facility; funds can also be collected over a shorter period to reduce the risk of insufficient funding associated with potential early closure.[919] The operators are not required to hold the funds in an external fund but are required to separate them from the other assets[920], i.e. internal segregated funds. In addition, there is no clear form of control over the funds, as it is largely up to the utilities to choose the form of control[921]. With all the reactors in LTE and hence no decommissioned commercial reactor, cost experiences for CANDU reactors are non-existent (see WNISR2018 for more details on the decommissioning process in Canada).

Japan

As of mid-June 2020, 27 reactors or 17.1 GW were permanently disconnected from the grid in Japan. The decommissioning of Tokai-1 is ongoing since 2001 and scheduled to be completed in 2025; the decommissioning of Fugen ATR started in 2008 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. The plans of the latter foresee the reactors to complete decommissioning in the mid-2040s, respectively mid-2050s for Ikata-1. Fukushima Daiichi-5 and -6 as well as the Units 1–4 have no completion date. In 2019, the 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$3.5 billion).[922]

Similar to other countries, Japan lacks experience in decommissioning—both, regarding the physical deconstruction and its financing. Japan, one of the early adopters of nuclear power, has not finished decommissioning of a single commercial reactor, and the only completed decommissioning project is the research reactor Japan Power Demonstration Reactor (JPDR), released as a greenfield site in 2002. Japan has not yet developed a decommissioning industry, which could provide efficient solutions applicable throughout a range of reactor types. The general regulation in Japan stipulates that the licensed operator of a nuclear power plant is responsible for decommissioning. The standard scenario in Japan includes a period of LTE of five to ten years before the hot-zone is deconstructed. The Japan Atomic Energy Commission (JAEC) reports in a 2019 White Paper, that the country is entering an era of massive nuclear plant decommissioning and urges operators to plan ahead to lower safety risks and costs requiring decades of and billions of dollars in finances. JAEC also urged utilities to learn from U.S. and European examples.[923]

Furthermore, the financial burden of the decommissioning projects is to be shouldered by the operators too. Historically, electric utilities had to establish tangible fixed assets for

919 - OECD/NEA, Costs of Decommissioning Nuclear Power Plants.

920 - Wuppertal Institut, "Comparison among different decommissioning funds methodologies for nuclear installations", EC-EAEC, 2007.

921 - Ibidem.

922 - *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.

923 - Mari Yamaguchi, "Japan urges nuke plants to prepare for decommissioning era", *Associated Press*, as published on *CTV News*, 2 September 2019, see https://www.ctvnews.ca/business/japan-urges-nuke-plants-to-prepare-for-decommissioning-era-1.4574443.

decommissioning during the period of operation through surcharges on the retail price of electricity and based on the output of a facility.[924] The Fukushima disaster in 2011, however, caused the shutdown of all operating plants by 2014 and thus a halt in the allocation of funds resulting in a shortage of decommissioning capital. In accordance with a Ministerial Ordinance in 2013[925], total asset retirement costs related to decommissioning are henceforth allocated by the straight-line method over the period of operation and safe storage. As a response to 3/11, the surcharges were decoupled from the electricity output of a reactor. To cover the financial shortage, many operators chose the strategy of intermediate storage (5–10 years) for their reactors in order to collect more money (Fugen ATR, Hamaoka-1 and 2, Tsuruga-1, Tokai-1).

It is likely that this strategy will increasingly be chosen for decommissioning projects in the short- and medium-term or the period of storage will possibly be prolonged due to financial deficits. The operators have to consider whether it is worth pursuing reactor restart with a possible single reactor lifetime extension of 20 years under the new regulations and, by doing that, enriching their reserves for decommissioning, or to choose the closure option, with the consequence of LTE in order to generate sufficient funding.

For some reactors, the restart option might be more expensive than closure. With no decommissioned commercial reactors and no available final waste disposal route, there is no actual financial experience, which makes estimates difficult. Additionally, it remains unclear which technical processes are included in the calculations. In 2015, the Power Generation Cost Analysis Working Group by Ministry for Economy Trade and Industry (METI) estimated an average of ¥71.6 billion (US$600 million) per reactor.[926] This average value is congruent with estimates published by the World Nuclear Association (WNA).[927] A recent study by the Institute of Energy Economics of Japan (IEEJ) expects decommissioning costs—with an average of ¥68 billion (US$560 million) per reactor.[928] That these estimates are likely to heavily underestimate real costs is illustrated by more recent estimates for the five latest Japanese reactors slated for decommissioning, where estimates have more than doubled to ¥160 billion (US$1.46 billion) per reactor.[929]

Another issue for the decommissioning process in Japan is that under ministerial guidelines, companies are permitted to temporarily divert decommissioning funds for other business purposes and thus risking that the funds are not available when needed. This has come to light in November 2017, with Japan Atomic Power Co using its decommissioning fund to cover costs of building the Tsuruga nuclear power station Units 3 and 4, which later were abandoned.[930]

924 - Ibidem; and Chubu Electric Power Company, "Quarterly Financial Report for the Nine Months Period Ended December 31, 2013", 31 January 2014, see http://www.chuden.co.jp/english/resource/ir/20140131_3rdqua_fr.pdf, accessed 24 April 2018.

925 - Ordinance No. 52 of the Ministry of Economy, Trade and Industry, 30 September 2013.

926 - Based on a calculation estimate for a sample plant, then for the other reactors multiplied with the generation output; the costs include an enclosure period of ten years. METI, "Report on Analysis of Generation Costs, Etc. for Subcommittee on Long-term Energy Supply-Demand Outlook", Power Generation Cost Analysis Working Group, May 2015.

927 - *WNN*, "Ikata 1 decommissioning gets regulatory approval", 29 June 2017; and WNA, "Japan's Nuclear Fuel Cycle", April 2018, see http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx, accessed 26 April 2018.

928 - Yuhji Matsuo, Kei Shimogori and Atsuhiko Suzuki, "Major Issues Regarding Nuclear Power Generation Costs Assessment in Japan", *IEEJ Energy Journal*, Vol. 10, No. 2, January 2015, see https://eneken.ieej.or.jp/data/6474.pdf.

929 - *Nikkei Asian Review*, "Japan to scrap 5 more nuclear reactors", 20 April 2017, see https://asia.nikkei.com/Economy/Japan-to-scrap-5-more-nuclear-reactors, accessed 26 April 2018.

930 - Tsuneo Sasai, "Japan Atomic Power in dire straits after diverting funds", *The Asahi Shimbun*, 17 November 2017.

South Korea

South Korea is running a large nuclear program, including 26 power reactors in various stages. As of mid-2020, 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 (see South Korea Focus for details) but was officially closed only in December 2019.[931]

In 2016, the operator Korea Hydro and Nuclear Power (KHNP) submitted an application to decommission Kori-1, the first reactor to enter the decommissioning stage in the country. A final and detailed decommissioning plan is under development and has to be submitted by KHNP to the regulator by 2021. Decommissioning of Kori-1 is estimated to start in mid-2022, last until December 2032, and cost around US$570 million or US$990/kW.[932] According to the Moon Administration's policy, South Korea will implement a nuclear phase-out policy in the long run. Existing capacity will not be extended after the completion of the units under construction and operating licenses not be extended beyond design lifetimes. Kori-2 is the next unit to be closed in 2023, followed by nine additional ones prior to 2030. In the next decades, South Korea is expected to build up its own decommissioning industry. Meanwhile, the Korean Atomic Energy Research Institute (KAERI) is taking steps to enhance decommissioning expertise and a series of contracts were signed to develop suitable technologies. In early 2020, South Korea announced plans to launch the construction of an institute that will develop technologies for the decommissioning of nuclear power plants, which is part of Government plans to access a global decommissioning market. Two establishments are planned: one focusing on LWRs and the other one PHWRs[933] (see WNISR2019 for details on the decommissioning process in South Korea).

France

In February 2020, France closed the first unit of the Fessenheim station, followed by Unit 2 in June 2020. These represent the first large PWRs to enter decommissioning in France. The closure increases the French closed reactor fleet to 14 reactors (8 GCR UNGG, 1 HWGCR, 2 FBR, 3 PWR) or 5.6 GW.[934] French regulation states that decommissioning has to begin immediately after reactor closure, but depending on the type of reactor, this could mean many years up to several decades.

With 56 Pressurized Water Reactors (PWRs), French utility EDF operates the most standardized fleet in the world, with the already closed units consisting mainly of Gas-Cooled Reactors (GCRs). In 2016, EDF shelved its ambitious plan of decommissioning its GCRs until 2036. In the next 15 years, the focus would lie on dismantling installations except for the reactors and their buildings. The plans foresee that the first reactor (Chinon A-1) would

931 - 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

932 - Jane Chung, "South Korea to complete dismantling of oldest nuclear reactor by 2032", *Reuters*, 19 June 2017, see https://www.reuters.com/article/us-southkorea-nuclear-idUSKBN19A02R, accessed 26 June 2019.

933 - David Dalton, "Seoul To Build Institute For Nuclear Decommissioning", *NucNet*, 22 April 2020, see https://www.nucnet.org/news/seoul-to-build-institute-for-nuclear-decommissioning-4-3-2020, accessed 11 May 2020.

934 - In addition, there is the military reactor G-1 on the Marcoule site, closed in 1968 and being decommissioned ever since.

only start dismantling in 2031; until then, the five remaining reactors would be in LTE. This new strategy aims to release the GCRs from regulatory control only by the beginning of the 22nd century.

In 2006, decommissioning of the 1200 MWe Fast Breeder Reactor (FBR) Superphénix started.[935] Since 2019, the first of three plugs that seal the reactor pressure vessel is being cut underwater using a remote-controlled robot.[936] In 2014, the end of decommissioning was anticipated in 2026[937], the current estimate is 2030–2035.[938] The reactor has entered the hot-zone-stage.

The HWR EL-4 on the Brennilis site was closed in 1985; since then decommissioning work has been ongoing—with some interruptions for legal reasons—and the reactor is still in the warm-up stage. The process depends on the construction of interim storage facilities and the granting of a complete dismantling license.[939] In 2019, it was announced that decommissioning will be further delayed, with the earliest possible completion in 2038. The decree formalizing that timeframe is expected to be signed by 2021.[940]

Decommissioning of the FBR Phénix, jointly operated by Électricité de France (EDF) and the French Alternative Energies & Atomic Energy Commission (CEA) and closed in 2009, is underway and the dismantling is operated by CEA, with Orano, and EDF. The decommissioning license was issued in 2016 and the spent fuel is currently being evacuated, the sodium drained and neutralized, i.e. the reactor is in the warm-up stage and full decommissioning is currently estimated to be achieved by 2045.[941]

Decommissioning of the plutonium-production GCRs G-2 and G-3 on the Marcoule site is the responsibility of the CEA. The reactors are defueled and put into LTE. The next steps, which are expected to begin in 2020, are the removal of the graphite from the reactor as well as the dismantling of the nuclear island, estimated to be completed sometime after 2040.[942]

Current cost estimates for EDFs closed reactors are around €6.5 billion (US$$_{2017}$7 billion), while EDF has only set aside €3.3 billion (US$$_{2016}$3.5 billion).[943] The costs for the legacy fleet have

935 - Decommissioning of the FBR Phénix is the scope of the French Alternative Energies & Atomic Energy Commission (CEA).

936 - Tristan Hurel, "À Creys-Malville, tout est prêt pour la découpe de la cuve de Superphénix", *Revue génerale nucléaire*, 14 January 2019 (in French), see https://www.sfen.org/rgn/creys-malville-pret-decoupe-cuve-superphenix, accessed 4 May 2020.

937 - Cour des Comptes, "Le coût de production de l'électricité nucléaire—Actualisation 2014", 27 May 2014.

938 - Tristan Hurel, "À Creys-Malville, tout est prêt pour la découpe de la cuve de Superphénix", *Revue Générale Nucléaire*, 14 January 2019, op. cit.

939 - EDF, "Déconstruction du site nucléaire de Brennilis", 2016 (in French), see https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-brennilis/presentation/dossier_de_presse_centrale_de_brennilis_2016.pdf, accessed 14 August 2018.

940 - Commission Locale d'Information des monts d'Arrée, "Réunion plénière de la CLI des monts d'Arrée du jeudi 5 juillet 2018", Press Release, 17 July 2018 (in French), see https://www.finistere.fr/content/download/36289/573127/file/2018-07-17%20CP%20Réunion%20plénière%20de%20la%20CLI%20des%20Monts%20d'Arrée%20du%205-07-2018.pdf, accessed 26 June 2019.

941 - Laurence Pickety, "Decommissioning of Sodium Fast Reactors: Presentation of French experience", Dismantling Division for civilian applications, Nuclear Energy Division, CEA, presented at the "Expert Panel on 'Monju' Decommissioning", July 2017, see http://www.mext.go.jp/b_menu/shingi/chousa/kaihatu/022/shiryo/__icsFiles/afieldfile/2017/08/23/1393867_02.pdf, accessed 14 August 2018.

942 - CEA, "Dossier de presse—Démantèlement", Commissariat ´à l'énergie atomique et aux énergies alternatives, 4 April 2015 (in French), see https://www.francetnp.gouv.fr/IMG/pdf/dossier_de_presse_demantelement_-_2015_v2.pdf, accessed 14 August 2018.

943 - EDF, "Consolidated financial statements at 31 December 2016", 2017.

increased steadily and doubled since 2001, when they were estimated to be around €3.3 billion (US$$_{2001}$2.9 billion).[944]

Until the Fessenheim station was disconnected from the grid, the only closed PWR was Chooz-A, which ceased operating in 1991. Since 2014, the reactor pressure vessel is being dismantled under water, hence the reactor is in the hot-zone-stage. EDF missed the ambitious target of completing decommissioning by 2016; the process is now expected to be completed by 2025.[945]

For Fessenheim, EDF foresees a post-operational stage lasting five years, during which the pressure vessel and the pools will be defueled and the spent fuel will be sent to La Hague. During this stage, the first non-nuclear installations will be dismantled too. After the post-operational stage, the partial dismantling of the reactor will begin in 2025, during which all the buildings except for the reactor building will be dismantled. During this period, the reactor will be isolated and under surveillance.[946] The dismantling of the nuclear island will be done in the final stage and last around five years; decommissioning of Fessenheim is thus scheduled to last around 20 years. EDF has undertaken to completely reclassify the site by 2041 and to keep it "for industrial use" which has yet to be defined.[947]

Table 14 · Status of Reactor Decommissioning in France (as of May 2020)

France	May 2018	May 2019	May 2020
"Warm-up-stage"	3	3	4
of which defueled	2	2	1
"Hot-zone-stage"	1	1	2
"Ease-off-stage"	0	0	0
LTE	8	8	8
Completed	0	0	0
of which released from regulatory control	0	0	0
Total Closed Reactors	**12**	**12**	**14**

Sources: Various, compiled by WNISR, 2020

For the entire PWR fleet, EDF expects total costs of around €23 billion (US$26 billion), which corresponds to around €300/kW (US$337/kW) of installed capacity, very low by international standards. In a recent report on the technical and financial feasibility of the decommissioning process, the French National Assembly alleged that EDF shows "excessive optimism".[948] The report concluded that decommissioning and clean-up will take more time, that the technical

944 - Cour des Comptes, "Le coût de production de l'électricité nucléaire—Actualisation 2014", 27 May 2014.

945 - Bertrand Martelet, "EDF's Expertise and Position in Nuclear Decommissioning", EDF, presented at the "1st World Nuclear Decommissioning & Waste Management Congress", 12–14 September 2016.

946 - Adélaïde Tenaglia, "Fessenheim: comment démantèle-t-on une centrale nucléaire?", *Le Parisien*, 19 February 2020 (in French), see http://www.leparisien.fr/economie/fessenheim-comment-demantele-t-on-une-centrale-nucleaire-19-02-2020-8262930.php, accessed 11 May 2020.

947 - Adrien Dentz, "Le complexe et coûteux démantèlement de la centrale nucléaire de Fessenheim", *Le Monde*, 20 February 2020 (in French), see https://www.lemonde.fr/economie/article/2020/02/20/le-complexe-et-couteux-demantelement-de-la-centrale-nucleaire-de-fessenheim_6030185_3234.html, accessed 11 May 2020.

948 - Mission d'information relative à la faisabilité technique et financière du démantèlement des installations nucléaires de base, "Rapport d'Information déposé en application de l'article 145 du règlement par la mission d'Information relative à la faisabilité technique et financière du démantèlement des installations nucléaires de base", N°4428, Commission du Développement Durable et de l'Aménagement du Territoire, French National Assembly, 1 February 2017 (in French), see http://www.assemblee-nationale.fr/14/pdf/rap-info/i4428.pdf, accessed 18 August 2018.

feasibility is not fully assured, and that the process will cost overall much more than EDF anticipates. Table 14 shows the current status of reactor decommissioning in France. (See WNISR 2018 for details)..

Lithuania

In Lithuania, there was no tangible progress on decommissioning of the two Soviet-Style RBMK-1500 reactors at the Ignalina station since WNISR2019. The two 1185 MW (each) reactors were closed in 2004 and 2009 respectively following a pre-requisite engagement for Lithuania to join the European Union. The two reactor cores are defueled, but the spent fuel in the pools has not yet been evacuated as the interim dry storage facility is delayed by more than 10 years.[949] The transfer of all spent fuel to the onsite storage facility is a prerequisite for the decommissioning license.[950] The decommissioning end date has, since 2011, been postponed by a further nine years to 2038. It is planned to decommission Ignalina to "brownfield" status.[951]

The European Union (EU) covers more than half of the costs for the decommissioning of Ignalina. A 2016 report by the European Court of Auditors concluded that the EU funding programs for decommissioning have not created the right incentives for timely and cost-effective decommissioning. The auditors concluded that the funding programs should be discontinued after 2020, when EU support for Lithuania will have totaled €1.8 billion (US$2 billion).[952] Between 2010 and 2015, costs increased by 67 percent to an estimated total of €3.4 billion (US$3.8 billion) and, as of 2015, the country faced a financing gap of €1.6 billion (US$1.8 billion). If high-level waste management and spent fuel disposal were included, the total costs were estimated at €6 billion (US$6.8 billion) and the financing gap would more than double to €4.2 billion (US$4.7 billion).[953] In addition, Lithuania faces a lack of qualified engineers for decommissioning, as this is the first RBMK decommissioning project anywhere; qualified international experts are also missing. (See WNISR2019 for details on the decommissioning in Lithuania).

949 - ENSREG, "Lithuania", Updated 6 February 2019, see http://www.ensreg.eu/country-profile/Lithuania, accessed 20 June 2019.

950 - Ignalina Nuclear Power Plant, "The list of documents of the State Enterprise Ignalina NPP required to issue a license for decommissioning and the schedule for their submission were agreed", 6 December 2018, see https://www.iae.lt/en/the-list-of-documents-of-the-state-enterprise-ignalina-npp-required-to-issue-a-license-for-decommissioning-and-the-schedule-for-their-submission-were-agreed/323, accessed 20 June 2019s

951 - 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.

952 - Ibidem.

953 - Ibidem.

Germany

The closure of Philppsburg-2 in Bavaria on 31 December 2019 increased the number of closed units in Germany to 30 or 18.3 GW (15 PWRs, 10 BWRs, 2 HTGR, 1 FBR, 1 HWGCR, 1 PHWR)[954]. Currently, decommissioning work is ongoing at 24 units:

- Eight reactors are in the warm-up stage: Biblis-A/B (both defueled), Grafenrheinfeld, Gundremmingen-B, Isar-1, Krümmel (defueled), Lingen (defueled), and Philippsburg-2;
- Eight reactors are in the hot-zone stage: AVR Jülich, Brunsbüttel, KNK II, Mülheim-Kärlich, Neckarwestheim-1, Obrigheim, Philippsburg-1, and Unterweser;
- Eight reactors are in ease-off zone stage: Greifswald units 1–5, MZFR, Rheinsberg, and Stade.

The thorium prototype reactor THTR-300 is the only reactor in LTE in the country. Only three reactors or 140 MW have been successfully released from regulatory control (BWR VAK Kahl, BWR HDR Großwelzheim, and the PHWR Niederaichbach). Of these early prototype reactors only VAK Kahl operated for a significant period of time (24 years). Decommissioning costs for VAK Kahl were given as €150 million (US$$_{2010}$215 million) in 2010[955] or ~€10,000/kW (~US$$_{2010}$14,366/kW).

Of the commercial reactors only Würgassen and Gundremmingen-A have de facto completed decommissioning. Gundremmingen-A, which started decommissioning in 1983, has finished the ease-off stage with the decontamination of the buildings only in 2016.[956] The latest cost estimate was around €2.2 billion (US$2.4 billion) or €9,000/kW (US$9,690/kW) for Gundremmingen-A, and €1 billion (US$1.1 billion) or €1,500/kW (US$1,615/kW) for Würgassen.[957] Due to its central position in Germany and the proximity to "Konrad", the geological disposal facility for low- and intermediate-level waste, the German federal company for interim storage (Gesellschaft für Zwischenlagerung or BGZ) is planning to build a logistic center at the Würgassen site in order to ensure the timely supply of the Konrad repository near Salzgitter.[958] Decommissioning of Stade (640 MW) was thought to be achieved by 2014, but ongoing difficulties due to unexpected contamination keeps delaying the project.

The legacy fleet of the former German Democratic Republic (GDR) consisting of Rheinsberg and the five units of Greifswald are currently in the ease-off stage. For both sites, the deferred dismantling strategy was chosen: The six pressure vessels were transported to the onsite interim storage facility (Zwischenlager Nord or ZLN), also operated by Entsorgungswerk für Nuklearanlagen or EWN, as were 17 steam generators and parts of the primary cooling system.

954 - PWR: Pressurized Water Reactor; BWR: Boiling Water Reactor, HTGR: High-Temperature Gas-Cooled Reactor; FBR: Fast Breeder Reactor; HWGCR: Heavy Water Gas Cooled Reactor; PHWR: Pressurized Heavy-Water Reactor.

955 - Katja Riedel, "Anfang und Ende des ersten deutschen Meilers", *Focus Online*, 17 June 2011 (in German), see https://www.focus.de/wissen/klima/tid-22667/versuchsatomkraftwerk-kahl-anfang-und-ende-des-ersten-deutschen-meilers_aid_637434.html, accessed 3 July 2020.

956 - Ines Bredberg et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2016", Bundesamt für kerntechnische Entsorgungssicherheit, 2017.

957 - Both sites cannot be released from regulatory control as the buildings are used for further decommissioning works or interim storage of wastes; see Ben Wealer et al., "Stand und Perspektiven des Rückbaus von Kernkraftwerken in Deutschland (»Rückbau-Monitoring 2015«)", DIW Berlin, TU Berlin, 2015.

958 - BGZ, "Logistikzentrum für Endlager Konrad entsteht in Würgassen", 2020 (in German), see https://bgz.de/2020/03/06/logistikzentrum-fuer-endlager-konrad-entsteht-in-wuergassen/, accessed 3 July 2020.

With the issuing of the permit for **Philippsburg-2** in December 2019, all eight reactors closed in the aftermath of the Fukushima events in March 2011 received the decommissioning permit from the regulatory authorities.[959] In addition, with the defueling of the **Krümmel** power plant in December 2019[960], all of these reactors, with the exception of Isar-1, are now defueled. **Grafenrheinfeld**, closed in 2015, is thought to be defueled by late-2020[961] and to enter the hot-zone works in 2021.

In early 2020, dismantling of the reactor internals was started at the **Unterweser** station, PreussenElektra tendered this work to a Westinghouse-GNS consortium. In 2019, PreussenElektra had subcontracted the reactor vessel segmentation to the GNS group.[962] Also during the year 2019:

- The first decommissioning work in the hot-zone of the **Brunsbüttel** reactor was carried out; Vattenfall had opted to start the decommissioning process with the most radioactive parts, e.g. with the dismantling of the internals of the reactor pressure vessel.[963]
- EnBW got the second and final permit for decommissioning work at the **Neckarwestheim** plant, this includes the dismantling of the biological shield, the lower part of the reactor pressure vessel, and the spent fuel pool.[964] Although, some decommissioning activities of the hot-zone-stage have already been carried out, i.e. in mid-2019 EnBW completed the dismantling and disassembly of the reactor pressure vessel internals.
- At the **Philippsburg-1** unit, EnBW is currently dismantling the internals and the head of the reactor pressure vessel.[965]

WNISR2020 counts those four reactors as in the hot-zone stage.

The **Lingen** reactor was put into LTE in 1988, and decommissioning started in 2018. The reactor is currently in the warm-up stage and RWE estimates that dismantling of the reactor pressure vessel could be started later this year. RWE tendered this work to the U.S. company Atkins.

The segmentation of the complete pressure vessel of the **Mülheim-Kärlich** and the vessel internals of the two **Biblis** units was also successfully tendered in 2019 to KORE, a consortium

959 - Bredberg et al., Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2018.

960 - *IWR Online*, "Atomkraftwerk Krümmel ist jetzt frei von Kernbrennstoff", Internationales Wirtschaftsforum Regenerative Energien, 16 December 2019 (in German), see https://www.iwr.de/ticker/letzter-castor-atomkraftwerk-kruemmel-ist-jetzt-frei-von-kernbrennstoff-artikel2075, accessed 11 May 2020.

961 - Irene Spiegel, "Kernkraftwerk: Rückbau startet 2021 in die heiße Phase", *Main-Post*, 31 January 2020 (in German), see https://www.mainpost.de/regional/schweinfurt/Kernkraftwerk-Rueckbau-startet-2021-in-die-heisse-Phase;art763,10397091#kommentare, accessed 11 May 2020.

962 - PreussenElektra, "Kernkraftwerk Unterweser: Zerlegearbeiten im Reaktordruckbehälter haben begonnen", 6 February 2020 (in German), see https://www.preussenelektra.de/de/unser-unternehmen/newsroom/pressemitteilungen/2020/KKUZerlegearbeitenimRDBhabenbegonnen.html, accessed 11 May 2020.

963 - Sven Jachmann, "Roboter zerschneidet das Herzstück des AKW Brunsbüttel", *NDR*, 28 November 2019 (in German), see https://www.ndr.de/nachrichten/schleswig-holstein/AKW-Brunsbuettel-Unterwasser-Roboter-im-Einsatz,akw344.html, accessed 11 May 2020.

964 - EnBW, "Kernkraftwerk Neckarwestheim: EnBW erhält zweite und letzte Genehmigung für den Rückbau von Block I", Press Release, 12 December 2019 (in German), see https://www.enbw.com/unternehmen/presse/kernkraftwerk-neckarwestheim-enbw-erhaelt-zweite-und-letzte-geneh.html, accessed 16 August 2020.

965 - EnBW Kernkraft GmbH, "TOP 4 – Aktuelles. Bericht der EnBW", presented at the 13. Sitzung der Informationskommission Philippsburg, 18 November 2019 (in German), see https://infokommission-kkp.de/documents/20596/218072/13.+Sitzung+TOP+4+Herr+Michels.pdf/af9f6ab9-7364-4e6c-8122-8c1de28e04a8, accessed 16 August 2020.

of EWN and Orano; while the segmentation of the vessel was awarded to Kraftanlagen Heidelberg, a Steag consortium.[966]

Table 15 shows the development in the decommissioning process since 2015 (see WNISR2018 for more details on decommissioning in Germany).

Table 15 · Status of Reactor Decommissioning in Germany (as of May 2020)

Germany	2015	May 2018	May 2019	May 2020
"Warm-up-stage"	10	11[a]	11	8
of which defueled	*0*	*3[a]*	*6[a]*	*4*
"Hot-zone-stage"	3	4	4	8
"Ease-off-stage"	9	8	8	8
LTE[b]	2	1[a]	1	1
Completed	4	5	5	5
of which released from regulatory control	*3*	*3*	*3*	*3*
Total Closed Reactors	**28**	**29**	**29**	**30**

Sources: Various, compiled by WNISR, 2020

Notes:

a - corrected from WNISR2019.

b - LTE or Long-Term Enclosure.

Italy

Following a referendum on the use of nuclear power in November 1987, triggered by the Chernobyl accident in April 1986, Italy no longer generated nuclear electricity.[967] The Pressurized Water Reactor (PWR) Enrico Fermi (Trino) produced its last kilowatt-hours in March 1987, the Gas-Cooled Reactor (GCR) Latina and the Boiling Water Reactor (BWR) Caorso in 1986 and the BWR Garigliano in 1978. Caorso is the only larger BWR (860 MW) Italy has to dismantle. Although Italy has only four units to dismantle, they have to deal with all three major reactor types. In 2017, Italy estimated the cost to decommission the four reactors and the entailed waste management at €7.2 billion ($\text{US\$}_{2017}$8.1 billion).[968] While this estimate does not include the disposal of high-level waste, it takes into account interim storage as well as the disposal of low- and intermediate-level waste. The estimate has almost doubled since 2004, when the total estimate was around €4 billion (US$4.5 billion), and more than tripled since the closure of the reactors, when decommissioning of the four reactors was projected to cost €2 billion (US$2.3 billion).[969]

In 1999, the state-owned company Sogin (Società Gestione Impianti Nucleari SpA) was established during the privatization process of Enel with the task to decommission Italy's

966 - RWE, "RWE setzt sicheren Abbau von Großkomponenten an drei Kernkraftwerksstandorten konsequent fort", Press Release, 18 October 2019 (in German), see https://www.group.rwe/-/media/RWE/documents/07-presse/rwe-nuclear-gmbh/2019-10-18-rwe-setzt-sicheren-abbau-von-grosskomponenten-konsequent-fort.pdf, accessed 26 July 2020

967 - WNISR considers the day of the last electricity generation as the closure date.

968 - David Dalton, "Italy's €7.2 Billion Decommissioning Cost Estimate Is Robust And Thorough, Says IAEA", *NucNet*, 21 September 2017, see https://www.nucnet.org/all-the-news/2017/09/21/italy-s-7-2-billion-decommissioning-cost-estimate-is-robust-and-thorough-says-iaea, accessed 3 May 2019.

969 - Wolfgang Irrek, Lars Kirchner and Lutz Jarczynski, "Comparison among different decommissioning funds methodologies for nuclear installations - Final Country Report (WP 1/ WP 3) Italy", Wuppertal Institut for Climate, Environment and Energy, 2007.

nuclear power plants as well as finding a national waste storage site. The shareholder of Sogin is the Ministry of Economy and Finance, while the strategic and operational directives come from the Ministry of Economic Development. At the same time, the initial strategy of long-term enclosure was changed to immediate dismantling. In 2004, it was estimated that Sogin would decommission the four reactors by 2024.

As there is no disposal facility available, the national decommissioning strategy is divided into two distinct phases with an estimated endpoint set at 2035:

- **First phase**: Decommissioning up to brownfield level; dismantling and waste treatment activities to be completed and the waste stored onsite. The duration of this phase depends on the availability of the final disposal facility.
- **Second phase**: Decommissioning of the reactor itself up to greenfield level; transfer of all the wastes to the repository and release of the site from regulatory control.

Italian legislation allows to authorize specific dismantling activities before the overall decommissioning plan is approved, if these activities benefit safety and radiation protection, some of which are underway, e.g., decontamination works, conditioning, construction of interim storages.

All four closed reactors are in the warm-up stage and have been defueled. The decommissioning licenses for the PWR **Enrico Fermi** (Trino) and the BWR **Garigliano** have been issued in 2012[970], although decommissioning works have been carried out at both stations since 1999. Sogin expects to complete decommissioning of Enrico Fermi to a brownfield site by 2031[971] and Garigliano by 2026.[972]

The decommissioning license for the BWR **Caorso** was issued in 2014.[973] The reactor has been defueled since 2010, when the spent fuel was sent to France for reprocessing. Caorso is currently in the warm-up stage and Sogin expects to conclude decommissioning by 2031.[974]

The only GCR in Italy, **Latina**, has been defueled in the early 1990s and the spent fuel sent to the U.K. for reprocessing. The decommissioning license for Latina was expected in 2018 but has only been granted in June 2020.[975] Since 2006, some decommissioning work has been carried out. Sogin currently expects to finish decommissioning up to the brownfield stage with waste storage onsite by 2027.[976] Subsequently, it will start with the decommissioning of the reactor building until it reaches the stage of greenfield site. Wastes are currently stored on-site, but the

970 - ISPRA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management - Fifth Italian National Report", National Centre for Nuclear Safety and Radiation Protection of the Institute for the Environmental Protection and Research, October 2017, see https://www.iaea.org/sites/default/files/6rm-italy.pdf.

971 - Sogin, "Trino nuclear power plant Vercelli - Decommissioning", 2019, see https://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/trino-nuclear-power-plant-vercelli.html, accessed 6 May 2019.

972 - Sogin, "Garigliano nuclear power plant", 2020, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/gariglianonuclearpowerplant/Pagine/default.aspx, accessed 3 July 2020.

973 - ISPRA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management - Fifth Italian National Report", October 2017, op. cit., p.13.

974 - Sogin, "Caorso nuclear power plant", 2020, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/caorsonuclearpowerplant/Pagine/default.aspx, accessed 6 July 2020.

975 - *WNN*, "Italy approves dismantling of Latina plant", 2 June 2020, see https://world-nuclear-news.org/Articles/Dismantling-of-Italys-Latina-plant-to-begin, accessed 6 July 2020.

976 - Sogin, "Latina nuclear power plant", 2020, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/Pagine/default.aspx, accessed 6 July 2020.

GCR Latina depends more than any other reactor on the opening of a national repository as the dismantling of the reactor will produce around 2,000 tons of highly radioactive graphite. (See WNISR2019 for details on the decommissioning process in Italy).

United Kingdom

Since 1977, 30 reactors or 4.7 GW were closed in the U.K., consisting mainly of small, first generation Gas-Cooled Reactors (GCRs), the Magnox design (26 reactors). Decommissioning of this legacy fleet is the responsibility of the public body Nuclear Decommissioning Authority (NDA). The NDA's strategy is to seal and store the biological shield, the pressure vessel, the external pressure circuit, and steam generators, while the actual dismantling of the reactors would begin only 85 years after the initial closure. This strategy is controversial and recent studies have shown that after 85 years, large amounts of the reactor waste will still not be suitable for disposal as low-level waste. In addition, the NDA realized that the reduction in decommissioning costs with the increase in deferral time is largely offset by the increased cost of preparing and managing the LTE of the reactor.[977]

Most of the waste will be conditioned on-site until the final disposal route is available. Some site decommissioning and remediation work has been undertaken at most sites with a major focus on defueling the reactors and emptying the ponds for the LTE state (all fuel will be transferred to Sellafield). Magnox Ltd., the service provider, is working towards a target of placing all the reactors into LTE by 2028. NDA's current plan indicates that it will take another 110 years to complete the core-mission of nuclear clean-up and waste management.[978]

The NDA sites are managed through private-sector consortia, while Sellafield is managed by the NDA itself. The NDA owns these sites and takes the role as the supervising and contracting authority and is turning the management over to the contractors, the so-called Site License Companies (SLC). The SLCs are the long-term shareholders of the sites, but the management is periodically opened to competition. The winner of these contracts (formerly tendered under EU public procurement law) acts as the Parent Body Organization (PBO), receives the shares of the SLC, and organizes the strategic management. This mechanism was thought to increase the efficiency of the procedure by opening the work to private contractors.[979] In a 2018-report, the House of Commons' Public Accounts Committee stated the NDA failed in both the procurement and management of the contract (one of the highest value and most important contracts awarded by the Government), e.g. the procurement process was overly complex, the contract was awarded to the wrong bidder, the settlement of legal claims reached nearly £100 million to a losing consortium, and the scale of the work was drastically under-estimated.[980]

977 - NDA, "Strategy—Effective from April 2016", Nuclear Decommissioning Authority, March 2016.

978 - Ibidem.

979 - Gordon MacKerron, "Multiple Challenges - Nuclear Waste Governance in the United Kingdom", in Nuclear Waste Governance. An International Comparison, ed. by Lutz Mez and Achim Brunnengräber, Springer VS, 2015.

980 - Public Accounts Committee, "The Nuclear Decommissioning Authority's Magnox contract (Summary)", U.K. House of Commons, 28 February 2018, see https://publications.parliament.uk/pa/cm201719/cmselect/cmpubacc/461/46103.htm#_idTextAnchor000, accessed 15 April 2018.

With the exception of Calder Hall 1–4, all the sites with Magnox reactors are operated by the SLC Magnox Ltd. From 2014 onwards, Cavendish Fluor Partnership was the PBO, but the contract officially ended in 2019. The Sellafield complex is operated by the SLC Sellafield Ltd., which since 2016 is a wholly owned subsidiary of the NDA. A detailed NDA review concluded that the PBO model was less suited for the complex, technical uncertainties at the Sellafield site.[981] Its mission to retrieve nuclear waste from some of the world's oldest nuclear facilities is planned to extend well into the 22nd century and the amounts of money involved are far greater than for other NDA sites. In July 2018, the NDA announced that Magnox Ltd will also become a subsidiary of the NDA.[982] Hence, since 2019, decommissioning of the entire legacy fleet, with the exception of the two Dounreay fast breeders,[983] is managed by the NDA. While the NDA funding largely comes directly from the Government, a segregated fund—the Nuclear Liabilities Fund—fed by payments from the only remaining nuclear power plant operator EDF Energy is in place for the operational fleet. (See WNISR2018 for details on the decommissioning process in the U.K.).

Spain

Spain has a national policy for decommissioning its reactors, specified by the official periodically updated "General Radioactive Waste Plan". In this plan, all decommissioning and waste management activities are developed by Enresa, the state-owned company Empresa Nacional de Residuos Radiactivos S.A. While the LTE strategy is applied for the Gas-Cooled Reactor (GCR) Vandellos-1, all LWRs are bound to be immediately dismantled to greenfield. Spain describes decommissioning and waste management as an essential public service and assigns these tasks to Enresa.[984]

The operator of the reactor is responsible for spent fuel, or must otherwise provide a spent fuel management plan, as this task falls under activities prior to decommissioning (e.g. defueling the reactor, conditioning of operational wastes).[985] Once these activities are completed, the decommissioning plan set up by Enresa must be approved, before the site is temporarily transferred to Enresa which then becomes the decommissioning licensee.[986] In general, this transition period of conditioning the waste, defueling the reactor and transferring the license is expected to last three years, while the decommissioning work is estimated to take 10 years. Although this seems short compared to the international average of 20 years for decommissioned reactors, if Enresa did finish the ease-off stage of the José Cabrera-1 reactor in the course of 2020, decommissioning would indeed have lasted only 10 years. When

981 - NDA, "Explained: the new model for managing Sellafield", Updated 1 April 2016, see https://www.gov.uk/government/publications/new-model-for-managing-sellafield/explained-the-new-model-for-managing-sellafield, accessed 16 May 2017.

982 - NDA and Magnox Ltd, "Magnox Limited to become a Nuclear Decommissioning Authority subsidiary", 2 July 2018, see https://www.gov.uk/government/news/magnox-limited-to-become-a-nuclear-decommissioning-authority-subsidiary, accessed 18 July 2018.

983 - Here a consortium of Cavendish Nuclear, Jacobs, and AECOM owns the SLC Dounreay Site Restoration Ltd.

984 - By Article 38 bis of Law 25/1964 of the Nuclear Energy Act.

985 - IAEA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management—Sixth Spanish National Report", Report drafted by the Spanish Ministry of Energy, Tourism and the Digital Agenda, the Nuclear Safety Council, the Spanish Radioactive Waste Management Agency, and the Spanish Electrical Industry Association, October 2017, see https://www.iaea.org/sites/default/files/national_report_of_spain_for_the_6th_review_meeting_-_english.pdf, accessed 11 August 2019.

986 - Ibidem.

decommissioning is complete and the "Closure Declaration" has been issued by the regulatory body—the Nuclear Safety Council or CSN[987]—the site will be returned to its former owner.[988]

Enresa is also responsible for managing the funds and liabilities for decommissioning. The external segregated fund is fed by two fees, the rate of which is regulated. The first fee is included in the electricity prices and used to finance waste management and decommissioning activities for those reactors closed prior to 2010 (José Cabrera and Vandellos-1). The second fee is for the reactors that have been operating beyond 2010 and stems from the income from operating the reactors.[989] After decommissioning starts, there are no more payments to the fund and in the case of a shortfall, it would be the full responsibility of the decommissioning licensee Enresa and hence the taxpayer to cover these costs.[990]

The latest "General Radioactive Waste Plan" estimates that decommissioning all of Spain's reactors will cost around €4.79 billion (~US$5.3 billion)[991] or around €585/kW (~US$645/kW), which is less than a third of the estimated decommissioning costs for the José Cabrera-1 reactor. The cost estimates for the latter have already doubled to around €259 million or €1,800/kW (US$292 million or US$2,100/kW), although this included cost estimates for waste processing, storage, and disposal.[992]

As of mid-2020, Spain had three closed reactors with a combined capacity of just over 1 GW. There was no tangible progress in decommissioning since WNISR2019. **José Cabrera-1**, a 241-MW Westinghouse PWR (1-Loop), which was closed in 2006 is still in the "ease-off stage", which is expected to be completed in 2020. Vandellos-1 is a 480-MW GCR designed and supplied by the French state agency CEA and was closed in 1990. Although some limited decommissioning work was carried out, WNISR considers the reactor as in LTE, as the main decommissioning will be carried out after an enclosure period of 25 years. The GE BWR at the Santa Maria de **Garoña** station was closed in 2012 due to economic reasons (see WNISR2018). The operator, Nuclenor (a joint venture of Endesa and Iberdrola), is currently defueling the reactor and plans to transfer the spent fuel to the interim storage facility as well as condition the operational wastes. In May 2020, Enresa has submitted an application for the transfer of ownership and decommissioning start to the Ministry for Ecological Transition and Demographic Challenge (MITECO), which Enresa expects for 2022.[993] The reactor is currently in the warm-up stage. (See WNISR2019 for details on the decommissioning process in Spain).

987 - CSN stands for Consejo de Seguridad Nuclear.

988 - Nuclear Energy Agency, "Radioactive Waste Management and Decommissioning in Spain", Organisation for Economic Co-operation and Development, October 2018, see https://www.oecd-nea.org/rwm/profiles/Spain_report.pdf, accessed 11 August 2019.

989 - IAEA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management—Sixth Spanish National Report", Report drafted by the Spanish Ministry of Energy, Tourism and the Digital Agenda, the Nuclear Safety Council, the Spanish Radioactive Waste Management Agency, and the Spanish Electrical Industry Association, October 2017.

990 - OECD/NEA, "Costs of Decommissioning Nuclear Power Plants", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, 2016.

991 - Ministerio para la Transición Ecológica y el Reto Demográfico and Government of Spain, "Borrador de 7o PGRR", Government of Spain, March 2020 (in Spanish), see https://energia.gob.es/es-es/Novedades/Documents/borrador_7_PGRR.pdf.

992 - OECD/NEA, "Costs of Decommissioning Nuclear Power Plants", 2016.

993 - *WNN*, "Decommissioning application submitted for Garoña", 26 May 2020, see https://www.world-nuclear-news.org/Articles/Decommissioning-application-submitted-for-Garona, accessed 26 May 2020.

Russia

In Russia, owner/operators are expected to have earmarked finances to cover the costs associated with decommissioning; for this purpose "special reserve funds" were established within the state corporation Rosatom.[994] Information about the Russian decommissioning fund has been inconclusive and contradictory; the terms "reserve" and "funds" have different institutional components.[995] In 2002, it was established that Rosatom should transfer money to a special reserve fund and that this amount should be 1.3 percent of the gross income generated by the sale of electricity. Money from the reserves is already spent on current decommissioning projects, though it is unclear how much.[996] In 2012, the percentage of the gross income generated by the sale of electricity that has to be put aside by Rosatom into the funds was increased to 3.2 percent.[997]

According to Rosatom, around €160 million (US$182 million) were accumulated in the "special reserve funds" by 2015.[998] To put the amount into perspective, this is roughly a fifth of the estimated decommissioning costs for the four Leningrad reactors alone. In addition, if the numbers from Lithuania's Ignalina site are taken as reference, the decommissioning of the four Leningrad RBMKs will cost more likely around €6 billion (US$6.7 billion).

It seems that in addition to technological challenges with dismantling, Russia has not set aside appropriate funding for decommissioning and has been heavily underestimating costs. It is unclear how Russia will handle this challenge in the future. One short-term option would be the long-term enclosure of closed reactors, while other units still generate income. A much riskier strategy that Russia has apparently adopted consists in the building of new reactors dedicated to generate income to replace ageing, life-extended units,[999] pushing the financing challenge further into the future.

In Russia, there was no tangible process in reactor decommissioning in 2019-20. As of mid-2020, Russia had eight closed reactors with a combined capacity of 2,107 MW consisting of two different reactor types: five first-generation Light-Water Gas-cooled Reactors (LWGR or RBMK)—among them one Chernobyl-type reactor—and three Soviet-style PWRs. WNISR considers them all in LTE (see WNISR2019 for details on the decommissioning process in Russia).

994 - Russian Federation, "The Fifth National Report of the Russian Federation on Compliance with the Obligations of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management", Prepared for the Sixth Review Meeting of the Joint Convention, IAEA, 2017.

995 - Kjersti Album et al., "Status of Russia's decommission fund", 2006.

996 - Kjersti Album, Tore Braend and Audun Randen Johnson, "How to pay? Financing decommissioning of nuclear power plants", Naturvernforbundet/Friends of the Earth Norway, 2017, see https://naturvernforbundet.no/getfile.php/13122760/Bilder/International%20projects/Report%20How%20To%20Pay%202017.pdf.

997 - Ibidem.

998 - Ibidem.

999 - Oskar Njaa, Nils Bøhmer and Charles Digges, "Russian Nuclear Power 2018", Bellona, 2018.

CONCLUSION ON REACTOR DECOMMISSIONING

Reactor decommissioning is an important element of the nuclear power system, but its technical and financial challenges are still largely underestimated. The size of the decommissioning activities is increasing rapidly, though: Assuming a 40-year average lifetime, a further 203 reactors will close by 2031 (reactors connected to the grid between 1980 and 1991); and an additional 122 will be closed by 2060; this does not even account for the 83 reactors which started operating before 1980, an additional 31 reactors in Long-term Outage (LTO) and the 52 reactors under construction as of mid-2020.

Around 60 percent of the closed reactors are located in Europe (90 in Western Europe and 23 in Central & Eastern Europe), followed by North America (44 reactors), and Asia (32 reactors). As of mid-2020, 169 units are globally awaiting or are in various stages of decommissioning, six more than in the first quarter of 2019. Since WNISR2019, only one reactor (La Crosse in the U.S.) completed the technical decommissioning, although the site is not yet released from regulatory control pending the final site survey and license reduction to the independent spent fuel installations on site.

These accomplished projects increased the total number of decommissioned reactors in the world from 19 to 20, with a combined capacity of around 6 GW. This represents only 7 percent of the total 84 GW withdrawn from the grid. The average worldwide duration of the decommissioning process, independent of the chosen strategy, is around 20 years, with a very high variance: the minimum of six years for the 22-MW Elk River plant, and the maximum of 42 years for the 17-MW CVTR (Carolinas-Virginia Tube Reactor), both small reactors, both in the U.S.

Around three-quarters of the closed reactors belong to the three major reactor technologies: Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR) and Gas-Cooled Reactor (GCR). Not one graphite-moderated reactor has yet been decommissioned (see case studies on France and the U.K.); this also holds true for Light Water Cooled and Graphite Moderated Reactors (LWGR) such as the Chernobyl-type RBMK. How to safely dismantle graphite-moderated reactors has yet to be demonstrated, not only in Russia but worldwide. The internationally preferred strategy is long-term enclosure, although some countries, including Italy and Lithuania, appear to be opting for a faster dismantling strategy. This remains to be seen, as the units in these countries are still in the warm-up stage and the Ignalina reactors in Lithuania are not even yet fully defueled.

The U.S. is still the most advanced country and has now with 14 completed projects by far the most decommissioned reactors, representing around three quarters of the world total. A new organizational model of selling decommissioning licenses to a contractor is gaining popularity in the country. Of the 12 reactors currently in the warm-up and ease-off stage as well as recently completed La Crosse, only Humboldt Bay was not transferred to a decommissioning licensee or contracted to one of the above companies. Already seven units were transferred to decommissioning companies, while another two transfers are pending for two units which are slated for decommissioning in the coming years. The waste management company EnergySolutions seems to be involved in most if not all U.S. decommissioning projects and plans to enter the Japanese market. Limited-liability decommissioning companies appear to operate according to business incentives that are starting to attract regulatory and legal attention. This new organizational model may allow to exploit economies of scale, but it relies on an efficient allocation of financial risks that has not yet been established.

The early nuclear states Canada, France, Russia and U.K. have not fully decommissioned one single reactor. Canada, Russia and U.K. put all their closed reactors into LTE, postponing decommissioning into the far future. Russia especially faces challenges concerning the decommissioning of its 11 RBMK reactors. Information about the Russian decommissioning fund has been inconclusive and contradictory.

Table 16 · Overview of reactor decommissioning in 11 selected countries (as of May 2020)

Country	Closed Reactors	Warm-up	Hot-zone	Ease-off	LTE	Completed	Percentage
USA	38	8	0	4	12	14	37%
UK	30	0	0	0	30	0	0%
Germany	30	8	8	8	1	5	17%
Japan	27	26	0	0	0	1	4%
France	14	4	2	0	8	0	0%
Russia	8	0	0	0	8	0	0%
Canada	6	0	0	0	6	0	0%
Italy	4	4	0	0	0	0	0%
Spain	3	1	0	1	1	0	0%
Lithuania	2	2	0	0	0	0	0%
South Korea	2	2	0	0	0	0	0%
Total	**164**	**55**	**10**	**13**	**66**	**20**	

Sources: Various, compiled by WNISR, 2020

POTENTIAL NEWCOMER COUNTRIES

ASIA

Suspended or Cancelled Programs

Indonesia is ranked sixteenth in terms of GDP and is the only one of three countries in the top 20, the others being Australia and Saudi Arabia, that have not deployed nuclear power. However, 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. The latest revision of the new and renewable energy policy mix mentions that nuclear will be only considered should the renewable energy target to produce 23 percent of power by 2025 not be achieved.[1000]

Kazakhstan operated a small fast breeder reactor, the BN 350 at Aktau, between 1972-1998 and is one of only three countries in the world to have abandoned commercial nuclear power, the others being Italy and Lithuania. In the following years, Kazakhstan has had a number of 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.[1001]

In June 2007, in **Thailand** the cabinet set up the Nuclear Power Program Development Office under the National Energy Policy Council and appointed an Infrastructure Establishment Committee, the Nuclear Power Utility subcommittee which is supervising the electricity utility (Electricity Generating Authority of Thailand – EGAT) in assessing the options for nuclear power. Since then various policy options and companies have been considered, and in April 2017, China and Thailand signed a nuclear co-operation agreement. At that occasion, 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."[1002] However, since then, there seem to have been no progress in developing nuclear power in Thailand.

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 says that they have chosen the VVER-1200 reactor design, which would be financed through an engineering, procurement and construction agreement via a soft loan from Russia. The reactors would provide power for domestic consumption, but some

1000 - Norton Rose Fulbright, "Renewable energy snapshot: Indonesia", April 2019, see https://www.nortonrosefulbright.com/en/knowledge/publications/0552a1f0/renewable-energy-snapshot-indonesia, accessed 4 July 2020.

1001 - 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 28 May 2020.

1002 - *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 28 May 2020.

of it could also be exported to neighboring countries such as Afghanistan.[1003] It was later stated that the intention was to choose a site, and have it licensed by September 2020,[1004] although this would appear extremely optimistic.

Vietnam, with its growing economy and energy demand for decades had been seen a perfect 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 1200 MW VVER reactors. Construction was expected to begin in 2014, with the turnkey project being owned and operated by the state utility Electricity of Vietnam (EVN). A second agreement was also signed with Japanese companies to develop an additional plant.[1005] 10.1 percent to 5.7 percent by 2030.[1006] 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 of safety and rising construction costs.[1007]

CONTINENTAL EUROPE

Belarus

Construction started in November 2013 at Belarus's first nuclear reactor at the Ostrovets power plant, also called Belarusian-1. Construction of a second 1200 MWe AES-2006 reactor started at the same site in June 2014.

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 scheduled to be commissioned in 2017 and the second in 2018.[1008] After various delays, the reactors are now close to completion and fuel loading of unit 1 is scheduled for July 2020, with grid connection expected later that year and Unit 2 following in 2021.[1009] However, during the summer of 2020, there were increasing concerns about the spread of the COVID-19 virus amongst the 4,000 Belarus and Russian workers on site.[1010] The imminency of completion is increasing the political attention the project is now facing.

1003 - *NEI Magazine*, "Uzbekistan's nuclear aspirations", 9 April 2019, see https://www.neimagazine.com/features/featureuzbekistans-nuclear-aspirations-7145738/, accessed 28 May 2020.

1004 - *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 28 May 2020.

1005 - *WNN*, "Vietnam prepares for nuclear power", 6 October 2011, see https://www.world-nuclear-news.org/Articles/Vietnam-prepares-for-nuclear-power, accessed 28 May 2020.

1006 - Viet Phuong Nguyen, "The fate of nuclear power in Vietnam", *Bulletin of Atomic Scientists*, 5 December 2016, see https://thebulletin.org/fate-nuclear-power-vietnam10245, accessed 28 May 2020.

1007 - *NIW*, "Briefs—Vietnam", *Nuclear Intelligence Weekly*, 28 November 2016.

1008 - *WNN*, "Contract signed for Belarusian reactors", 11 October 2011, see https://www.world-nuclear-news.org/Articles/Contract-signed-for-Belarusian-reactors, accessed 28 May 2020.

1009 - *NEI Magazine*, "Belarus 1 prepares for fuel loading", 14 May 2020, see https://www.neimagazine.com/news/newsbelarus-1-prepares-for-fuel-loading-7924095/, accessed 30 May 2020.

1010 - Gary Peach, "Belarus Prepares Reactor Launch Despite Covid-19 Surge", *NIW*, 29 May 2020.

The 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.[1011] 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 a year for half of the selected funds and "six-month LIBOR in dollars (now 1.72%) plus 1.83% per annum" for the other half.[1012] 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.[1013] The Minsk Government is also seeking to reduce the interest rate and to delay the start of payments from April 2021 to April 2023.[1014]

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. In May 2016, the respective startup months were specified as November 2018 and July 2020.[1015] In August 2016, the reactor pressure vessel of unit one slipped and fell two meters before hitting the ground, during installation. This led to an eight-month delay, while it was replaced.[1016]

The official cost of the project has increased by 26 percent, to 56 billion Russian rubles in 2001-prices (US$$_{2001}$1.8 billion).[1017] However, the falling exchange rate of the ruble against the dollar significantly affects the dollar price of the project.

The project is the focus of international opposition and criticism, with formal complaints from the Lithuanian Government[1018] that has published a list of fundamental problems of the project. These include claims of major construction problems, 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.[1019] Then, in April 2019, a meeting of the Espoo Convention voted by 30 to 6 that Belarus had violated the convention's rules while choosing Ostrovets as the site for a nuclear power plant.[1020]

1011 - *NIW*, "Belarus, Aided by Russia and Broke, Europe's Last Dictatorship Proceeds With NPP", 28 September 2012.

1012 - *NEI*, "Finance discussed as unit 1 of Belarus NPP prepares for start-up", 14 February 2020, see https://www.neimagazine.com/news/newsfinance-discussed-as-unit-1-of-belarus-npp-prepares-for-start-up-7773070/, accessed 28 May 2020.

1013 - *NEI*, "Finance Discussed as Unit 1 of Belarus NPP Prepares for Start-Up", 14 February 2020, op. cit.

1014 - Gary Peach, "Belarus Prepares Reactor Launch Despite Covid-19 Surge", *NIW*, 29 May 2020.

1015 - *WNN*, "Reactor vessel assembly completed for second Belarusian unit", 26 May 2016, see http://www.world-nuclear-news.org/NN-Reactor-vessel-assembly-completed-for-second-Belarusian-unit-26051601.html, accessed 28 May 2020.

1016 - *NIW*, "Briefs – Belarus", 15 February 2019.

1017 - *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 30 May 2020.

1018 - 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 30 May 2020.

1019 - UNECE, "Findings and recommendations with regard to communication ACCC/C/2014/102 concerning compliance by Belarus", UN Economic Commission for Europe, presented at the 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, 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 30 May 2020.

1020 - *NIW*, "Briefs – Belarus", 15 February 2019.

In April 2017, an accord was signed by all parties in the Lithuanian Parliament noting that all necessary measures should be taken to stop the construction of Ostrovets and "at least to ensure that the electricity produced in this nuclear power plant will not be allowed into Lithuania nor will it be allowed to be sold on the Lithuanian market under any circumstances".[1021]

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.[1022]

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."[1023] 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.[1024]

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 put out a joint declaration that they would oppose electricity purchases from the nuclear power plant.[1025] In addition, in May 2020, the Lithuanian Parliament passed a resolution on Energy Independence proposing that the Government take technical means to block electricity from Belarus.[1026] 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

1021 - Lithuanian Parliament, "Accord between the Parliamentary Political Parties of the Republic of Lithuania on Joint Actions Against the Unsafe Nuclear Power plant in Astraveyets", April 2017.

1022 - ENSREG, "Belarus Stress Test National Report", European Nuclear Safety Regulators Group, 22 May 2018, see http://www.ensreg.eu/news/belarus-stress-test-national-report, accessed 30 May 2020.

1023 - Council of the European Union, "Report on the implementation of the obligations under the Convention on Nuclear Safety - 8th Review Meeting of the Contracting Parties", 19 June 2019, see https://data.consilium.europa.eu/doc/document/ST-10365-2019-ADD-1/en/pdf, accessed 30 May 2020.

1024 - Belta, "Fulfillment of national action plan in wake of Belarusian nuclear power plant stress tests reviewed", News from Belarus, 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 10 June 2020.

1025 - 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 30 May 2020.

1026 - LRT, "Lithuanian parliament ups the ante on Belarus nuclear plant", 5 May 2020, see https://www.lrt.lt/en/news-in-english/19/1175343/lithuanian-parliament-ups-the-ante-on-belarus-nuclear-plant, accessed 30 May 2020.

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.[1027]

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 build 6 GW of nuclear power capacity with the first reactor starting up by 2024.[1028] The reactor types then under consideration included AREVA's EPR, Westinghouse's AP1000, and Hitachi-GE's 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.[1029] At that time, the project was estimated at US$13–19 billion and construction was to begin in 2019.[1030] 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.[1031] That did not happen.

In late 2017, the Energy Minister, Krzysztof Tchórzewski, said that he would like to see Poland build three nuclear reactors, at five-yearly intervals, the first to operate in 2029, with each unit costing US$7 billion.[1032] In November 2018, the Government published a draft strategic energy development program, which called for the construction of four reactors (providing between 6–10 GW of capacity) by 2040, with the first in operation by 2033[1033]—a decade later than a plan published just five years earlier—with up to six units with a combined capacity of 6-9 GWe to be put into operation until 2043.[1034] The Ministry of Energy envisages the site

1027 - Gary Peach, "Belarus Prepares Reactor Launch Despite Covid-19 Surge", *NIW*, 29 May 2020.

1028 - Lukasz Kuzniarski, "Polish Nuclear Power Programme", Ministry of Economy, 17 March 2014, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-03-17-03-21-WS-INIG/DAY2/COUNTRY/L_Kuzniarski_POLAND_IAEA_workshop_Seoul_2014.pdf, accessed 30 May 2020.

1029 - *NIW, "Briefs – Poland", 8 February 2013.*

1030 - *The Economist*, "Going nuclear", 31 January 2014, see https://www.economist.com/blogs/easternapproaches/2014/01/polish-energy, accessed 30 May 2020.

1031 - *Nucnet*, "Amec Wins USD 430 Million Contract To Support Polish New-Build", 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 30 May 2020.

1032 - Wojciech Zurawski, "Poland may have first nuclear power plant by 2029", *Reuters*, 6 September 2017, see https://www.reuters.com/article/poland-nuclear/poland-may-have-first-nuclear-power-plant-by-2029-idUSL8N1LN222, accessed 30 May 2020.

1033 - Gary Peach, "Power Demand in Poland Bolsters Case for Nuclear", *NIW*, 11 November 2018.

1034 - *WNN*, "Poland sets financing target for nuclear plant : Nuclear Policies", 19 November 2019, see https://www.world-nuclear-news.org/Articles/Poland-sets-financing-target-for-nuclear-plant, accessed 30 May 2020.

selection for the first plant in 2020, while the technology would be chosen in 2021.[1035] While the plans are being developed, Poland is angering political parties and its neighbors with sparsity of information. In November 2019, in a letter sent to German Economy Minister Peter Altmaier, MP Sylvia Kötting-Uhl said the fact that Germany had not heard of the matter thus far was "incomprehensible and unacceptable" and that it was ignoring international law, such as the Espoo Convention.[1036]

The financing model being proposed by the Government is not clear, although Poland's secretary of state in the Chancellery of the Prime Minister and Government plenipotentiary for strategic energy infrastructure said in November 2019 that the Government plans to set up a special-purpose company in which it will own a 51 percent stake, with the remaining 49 percent to be held by a foreign partner. PGE could be a shareholder in that special-purpose company.[1037] PGE's incoming CEO Wojciech Dąbrowski, however, declared in May 2020 that although he was in favor of Poland developing nuclear power, "PGE will not be an investor in a nuclear project".[1038]

In 2019, renewable energy deployment continued to grow and, by mid-2020 is accounting for 10 GW of capacity, with the fastest developing renewable technology being solar power.[1039]

AFRICA

In continental Africa, only South Africa has an operating nuclear power plant. This is despite sporadic support from national Governments and encouragement from international vendors, now particularly China and Russia. According to the World Nuclear Association (WNA), China has agreements with (but no plants under construction) in Kenya, Sudan and Uganda, while Russia signed agreements with Algeria, Ethiopia, Morocco, Nigeria, Sudan, Rwanda and Zambia.[1040]

Across the continent, electricity generation increased from 670 TWh in 2010 to 870 TWh in 2018, with natural gas and coal (the latter largely in South Africa) accounting for 40 percent and 30 percent respectively, hydropower representing a further 16 percent, oil 9 percent, non-hydro renewables (solar, wind etc.) 3 percent and nuclear less than 2 percent. Africa does however have a significant role for the global nuclear industry with Namibia and Niger the world's fourth- and fifth-largest uranium producers.

1035 - *WNN*, "Poland already preparing for nuclear plant, says energy minister", 16 May 2020, see https://world-nuclear-news.org/Articles/Poland-already-preparing-for-nuclear-plant,-says-e, accessed 30 May 2020.

1036 - Florence Schulz, "Poland's first nuclear power plants are attracting criticism - from neigbours", *Euractiv*, 26 February 2020, see https://www.euractiv.com/section/energy/news/polands-first-nuclear-power-plants-are-attracting-criticism-from-its-neigbours/, accessed 4 July 2020.

1037 - *WNN*, "Poland Sets Financing Target for Nuclear Plant", 19 November 2019, see https://world-nuclear-news.org/Articles/Poland-sets-financing-target-for-nuclear-plant, accessed 30 May 2020.

1038 - Adam Easton, "Poland's PGE puts forward plan to spin off coal, focus on renewables", *S&P Global*, 13 May 2020, see https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/poland-s-pge-puts-forward-plan-to-spin-off-coal-focus-on-renewables-58602638, accessed 4 July 2020.

1039 - *The First News*, "Poland generates 10GW from renewables, solar fastest growing source", 22 June 2020, see https://www.thefirstnews.com/article/poland-generates-10gw-from-renewables-solar-fastest-growing-source-13528, accessed 23 June 2020.

1040 - WNA, "Emerging Nuclear Energy Countries | New Nuclear Build Countries", March 2020, see https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx, accessed 4 July 2020.

For more information on the South African program see section on South Africa in Annex 1, and on Egypt's program see dedicated section in Middle East Focus.

While the WNA lists Ethiopia, Ghana, Kenya, Namibia, Nigeria, Rwanda, Senegal, Tanzania, Uganda and Zambia as having considered nuclear power at one time or another in West, Central or Southern Africa,[1041] the vast majority of these are little more than political statements of support designed to increase diplomatic links with key infrastructure providers and recipients. However, over the past year some developments have occurred. Of significance is Rwanda that 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.[1042] 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 International Atomic Energy Agency (IAEA)to develop plans for up to 4,000 MWe of nuclear capacity by 2025, which are obviously not achievable, at least in the originally envisaged timeframe.[1043]

1041 - WNA, "Emerging Nuclear Energy Countries", January 2018, see http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx, accessed 24 April 2018.

1042 - Katya Golubkova, "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 4 July 2020.

1043 - *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 4 July 2020.

SMALL MODULAR REACTORS

Small Modular Reactors (SMRs)[1044] continue to be the focus of much of the discussion about the future of nuclear power. These have so far been suffering many of the development problems experienced in large nuclear power plant projects, especially deadlines for licensing and construction being pushed back and costs increasing. However, in the case of SMRs, most designs are purely theoretical ones, and no real reactors have been constructed based on that design. Going by current trends, they are unlikely to ever be constructed beyond a few prototypes. What follows is an update of earlier analysis (in particular WNISR2015 and WNISR2017 and WNISR2019) on SMR programs in selected countries (in alphabetical order).

ARGENTINA

The CAREM-25[1045] reactor has been under construction in Argentina since February 2014.[1046] The idea dates back to 1984, when the concept was presented at an IAEA Conference on Small Modular Reactors.[1047] CAREM-25 was projected to receive its first fuel load in the second half of 2017.[1048] By 2018, this date had been pushed back to 2020.[1049] An update from July 2019 suggested that overall progress was around 55 percent, but enough for the spokesperson from the National Atomic Energy Commission of Argentina (CNEA) to claim that "Argentina is leading the PWR [Pressurized Water Reactor] SMR design-construction process with the FOAK [First Of A Kind] CAREM25".[1050]

Despite such claims, it is clear that the commissioning date has been significantly delayed. In November 2019, an important contracting company, Techint Engineering & Construction, halted work on the project "citing late payment from the government, design changes and late delivery of technical documentation".[1051] Nucleoeléctrica Argentina SA announced in April 2020 that construction is to be resumed,[1052] but there is no update about when the reactor might become operational.

1044 - The acronym SMR is also used to mean "small and medium-sized reactor" by the IAEA. For the IAEA, a "small" reactor is one having electrical output less than 300 MWe and a "medium" reactor is one having a power output between 300 MWe and 700 MWe.

1045 - CAREM stands for Central Argentina de Elementos Modulares.

1046 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 24 May 2015.

1047 - Silvia Lucila Molina, Natalia Sofía Tucci Branco and María Noelia Dusau, "CAREM Reactor: An Innovative and Achievable Option for Enhancing Nuclear Energy Supply", presented at the INTER JURA 2018, International Nuclear Law Association, 4 November 2018, see https://emirates.meeting-app.events/inla2018/congress-papers/, accessed 29 June 2019.

1048 - *WNN*, "Construction of CAREM Underway", 10 February 2014, op. cit.

1049 - *NEI*, "Progress for Argentina's CAREM SMR", 9 May 2018, see http://www.neimagazine.com/news/newsprogress-for-argentinas-carem-smr-6144828, accessed 20 May 2018.

1050 - Ignacio de Arenaza, "CAREM25 Current Status", presented at the 17th INPRO Dialogue Forum on Opportunities and Challenges in Small Modular Reactors, 2 July 2019, see https://nucleus.iaea.org/sites/INPRO/df17/IV.2-de%20Arenaza-CAREM.pdf, accessed 4 July 2020.

1051 - *Global Construction Review*, "Techint halts work on Argentina's pioneering small modular reactor scheme", 15 November 2019, see http://www.globalconstructionreview.com/news/techint-halts-work-argentinas-pioneering-small-mod/, accessed 24 June 2020.

1052 - *WNN*, "Argentinean projects to resume after hiatus", 21 April 2020, see https://world-nuclear-news.org/Articles/Argentinean-projects-to-resume-after-hiatus, accessed 24 June 2020.

CANADA

Over the past few years, a variety of officials in Canada, both at the federal level and provincial levels, have been advocating for SMRs and would like the country to be among the first to deploy an SMR. Talk about SMRs increased after December 2019, when the Premiers of Ontario, Saskatchewan, and New Brunswick announced that they would work together to research and build SMRs.[1053] Saskatchewan has since included the development of SMR technology amongst its goals for 2030,[1054] and announced that it is setting up a dedicated office to coordinate policy.[1055]

The most concrete proposal that is starting to move forward is from a company called Global First Power to develop a demonstration project, the Micro Modular Reactor Project, at the Chalk River Laboratories site in the province of Ontario.[1056] In March 2019, the proponent submitted an application for a license to the Canadian Nuclear Safety Commission (CNSC) to construct this design and the CNSC has determined the scope for the necessary environmental assessment for the project.[1057] Since the beginning, Ontario Power Generation (OPG), the country's largest operator of nuclear power plants, has supported the project, and in June 2020 formally joined Global First Power and Ultra Safe Nuclear Corporation as a partner.[1058]

According to its proponents, the Micro Modular Reactor Project is intended to be "a commercial demonstration reactor" and "a model for future deployment opportunities where the low-carbon and versatile power from an SMR could support the energy needs of remote communities and heavy industry".[1059] This follows the ideas set out in the 2018 SMR Roadmap put out by provincial utilities, Natural Resources Canada and Atomic Energy of Canada Limited (AECL), which talked of "three potential applications for SMRs in Canada: on-grid, heavy industry, and remote communities" and multiple designs to meet these "different energy demands".[1060] But an evaluation of the net electricity demand from remote mines and communities shows that these markets are insufficient to develop the facilities needed to manufacture these SMRs, and the costs of the electricity any reactors small enough to power a remote mine or community would be prohibitively high.[1061]

1053 - Elise von Scheel, "Group of premiers band together to develop nuclear reactor technology", *CBC News*, 1 December 2019, see https://www.cbc.ca/news/politics/group-of-premiers-band-together-to-develop-nuclear-reactor-technology-1.5380316, accessed 3 July 2020.

1054 - *WNN*, "Saskatchewan includes SMRs in growth plan", 15 November 2019, see https://world-nuclear-news.org/Articles/Saskatchewan-includes-SMRs-in-growth-plan, accessed 5 July 2020.

1055 - David Giles, "Saskatchewan's nuclear secretariat tasked to develop, deploy small modular reactors", *Global News*, 24 June 2020, see https://globalnews.ca/news/7102249/saskatchewan-nuclear-secretariat-small-modular-reactors/, accessed 3 July 2020.

1056 - GFP, "MMR Project at Chalk River", Global First Power, 2019, see https://www.globalfirstpower.com/proposed-project-at-chalk-river-ont, accessed 3 July 2020.

1057 - CNSC, "New reactor facility projects", Canadian Nuclear Safety Commission, 6 March 2020, see http://nuclearsafety.gc.ca/eng/reactors/power-plants/new-reactor-facilities/index.cfm, accessed 3 July 2020.

1058 - OPG, "OPG marks major milestone in SMR development in Canada", Ontario Power Generation, 29 June 2020, see https://www.opg.com/story/opg-marks-major-milestone-in-smr-development-in-canada/, accessed 3 July 2020.

1059 - Ibidem.

1060 - Canadian Small Modular Reactor Roadmap Steering Committee, "A Call to Action: A Canadian Roadmap for Small Modular Reactors", 2018, see https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf, accessed 3 July 2020.

1061 - 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,* 2020, see https://www.sciencedirect.com/science/article/abs/pii/S030142152030327X, accessed 3 July 2020.

Canada's other initiative to promote SMRs is the CNSC's "pre-licensing vendor design review", an optional service for SMR vendors that takes place in three phases. The first phase involves "an overall assessment of the vendor's nuclear power plant design against the most recent CNSC design requirements for new nuclear power plants in Canada" as well as "all other related CNSC regulatory documents and Canadian codes & standards". The second phase focuses on "identifying any potential fundamental barriers to licensing the vendor's nuclear power plant design in Canada". The third phase "allows the vendor to follow-up on certain aspects of Phase 2 findings by:

- seeking more information from the CNSC about a Phase 2 topic; and/or
- asking the CNSC to review activities taken by the vendor towards the reactor's design readiness, following the completion of Phase 2".[1062]

Table 17 · Vendor Design Review Service Agreements in Force Between Vendors and the CNSC (as of mid-2020)

Vendor	Name of design and cooling type	Approximate capacity (MWe)	Applied for	Review start date	Status
Terrestrial Energy Inc.	IMSR Integral Molten Salt Reactor	200	Phase 1	April 2016	Complete
			Phase 2	December 2018	Assessment in progress
Ultra Safe Nuclear Corporation	MMR-5 and MMR-10 High-temperature gas	5-10	Phase 1	December 2016	Complete
			Phase 2	Pending	Project start pending
LeadCold Nuclear Inc.	SEALER Molten Lead	3	Phase 1	January 2017	On hold at vendor's request
Advanced Reactor Concepts Ltd.	ARC-100 Liquid Sodium	100	Phase 1	September 2017	Complete
Moltex Energy	Moltex Energy Stable Salt Reactor, Molten Salt	300	Phase 1 and 2	December 2017	Phase 1 assessment in progress
SMR, LLC. (A Holtec International Company)	SMR-160 Pressurized Light Water	160	Phase 1	July 2018	Assessment in progress
NuScale Power, LLC	NuScale Integral pressurized water reactor	60	Phase 2*	January 2020	Assessment in progress
U-Battery Canada Ltd.	U-Battery High-temperature gas	4	Phase 1	February 2017	Project start pending
GE-Hitachi Nuclear Energy	BWRX-300 boiling water reactor	300	Phase 2*	January 2020	Assessment in progress
X Energy, LLC	Xe-100 High-temperature gas	75	Phase 2*	July 2020	Project start pending

Source: CNSC Website, 2020

Note: *NuScale Power, X Energy, and GE-Hitachi, have opted to have Phase 1 objectives be addressed within the Phase 2 scope of work.

Over the past year, the ARC-100 design completed the Phase 1 review process and in October 2019 CNSC staff publicly shared their conclusions, including the specification that "additional work is required by ARC to address the findings raised as part of this review, including the need to implement planned changes to its management system" and a listing of

1062 - CNSC, "Pre-Licensing Vendor Design Review", Canadian Nuclear Safety Commission, 15 June 2020, see http://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm, accessed 4 July 2020.

a number of issues that needed resolution.[1063] The other new development is the addition of the Xe-100 high-temperature gas cooled reactor to the list of reactors undergoing review. As of July 2020, CNSC lists 12 designs (see Table 17 and Table 18) at various stages of this process, including designs like ARC-100 that are listed having completed Phase 1 but without having any ongoing further review.

Table 18 · Vendor Design Review Service Agreement Between Vendors and the CNSC Under Development

Vendor	Name of design and cooling type	Approximate capacity (MWe)	Applied for	Application received
StarCore Nuclear	StarCore Module High-temperature gas	10	Phase 1 and 2	October 2016
Westinghouse Electric Company, LLC	eVinci Micro Reactor solid core and heat pipes	Various, up to 25 MWe	Phase 2*	February 2018

Source: CNSC Website, 2020

Note: *Phase 1 objectives will be addressed within the Phase 2 scope of work.

CHINA

China continues to construct the High-Temperature Reactor (HTR-PM) at Shidaowan (Shidao Bay) in the eastern Shandong province. It consists of two 100 MW modules driving one 200 MW turbine.

The HTR-PM received final approval from China's cabinet and its national energy bureau in 2011,[1064] construction commenced in December 2012.[1065] At that time, the Huaneng Shandong Shidao Bay Nuclear Power Company Ltd. (HSNPC), builder and operator of the unit, announced that construction would "take 50 months, with 18 months for building, 18 months for installation and 14 months for pre-commissioning".[1066] HSNPC stated that the power plant would start generating commercial electricity by the end of 2017. That did not happen.

In January 2018, a construction company involved in installing the pressure vessel head stated that the reactor was "expected to be connected to the grid and start electricity generation this year" (in other words, in 2018).[1067] Again, that did not happen.

In March 2020, China National Nuclear Corporation (CNNC) announced that the "reactor pressure vessel, steam generator, and hot gas duct of the second reactor" were paired and

1063 - CNSC, "Phase 1 Pre-Licensing Vendor Design Review Executive Summary: ARC Nuclear Canada Inc.", Canadian Nuclear Safety Commission, 1 October 2019, see http://cnsc.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/arc-nuclear-canada-executive-summary.cfm, accessed 4 July 2020.

1064 - Keith Bradsher, "China Building Nuclear Reactors With Radically Different Design", *New York Times*, 24 March 2011, see http://www.nytimes.com/2011/03/25/business/energy-environment/25chinanuke.html, accessed 24 April 2012.

1065 - Zuoyi Zhang et al., "The Shandong Shidao Bay 200 MWe High-Temperature Gas-Cooled Reactor Pebble-Bed Module (HTR-PM) Demonstration Power Plant: An Engineering and Technological Innovation", *Engineering*, March 2016.

1066 - *NucNet*, "China Begins Construction Of First Generation IV HTR-PM Unit", The Communications Network for Nuclear Energy and Ionising Radiation, 7 January 2013, see http://www.nucnet.org/all-the-news/2013/01/07/china-begins-construction-of-first-generation-iv-htr-pm-unit, accessed 10 January 2013.

1067 - *WNN*, "First HTR-PM vessel head in place", 4 January 2018, see http://www.world-nuclear-news.org/NN-First-HTR-PM-vessel-head-in-place-0401185.html, accessed 9 April 2018.

connected.[1068] According to a June 2020 presentation, "criticality and power operation" are now scheduled for 2021,[1069] at least four years later than originally envisaged. There appear to be no plans to construct more reactors of the same design due to high economic costs (see also China Focus and previous WNISRs).

Other SMR designs that are under development include the ACPR50 and ACPR100 from China General Nuclear (CGN) and the ACP100 from China National Nuclear Corporation (CNNC). In July 2019, it was reported that CNNC is starting to "build an ACP100 small modular reactor at Changjiang in Hainan, an island province in the south of the country" and the formal construction was to start at the end of 2019.[1070] However, this has not been confirmed. One reason why the ACP100 might not be deployed in China, at least at scale, is that even CNNC admits that in the case of the proposed ACP100 demonstration project, the construction cost per kilowatt "is 2 times higher than that of [a] large NPP [nuclear power plant]".[1071]

INDIA

India's Department of Atomic Energy (DAE) has been developing the Advanced Heavy Water Reactor (AHWR) design since the 1990s,[1072] but the reactor still seems far from being complete. The AHWR was one way for the DAE to get experience with the use of thorium, a long-standing dream for the organization.[1073] Because thorium cannot be used as fuel, the AHWR has to use large quantities of some other fissile material that can be fissioned with low-energy neutrons in addition to thorium. The first AHWR design utilized plutonium, but subsequently DAE developed another version using low enriched uranium (but close to 20 percent enrichment in uranium-235) instead of plutonium.[1074]

By the end of the 1990s, the DAE had started talking about construction of the AHWR. In 2000, the head of the Nuclear Power Corporation of India projected that construction would start in 2004 and be finished by 2011.[1075] In a 2001 interview, the Director of the Bhabha Atomic Research Centre projected that "the Detailed Project Report" for the AHWR "will be ready

1068 - *WNN*, "Key components of second HTR-PM reactor connected", 25 March 2020, see https://www.world-nuclear-news.org/Articles/Key-components-of-second-HTR-PM-reactor-connected, accessed 29 April 2020.

1069 - Fu Li, "Chinese HTR Program", presented at the IFNEC SMR Webinar Series, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 5 July 2020.

1070 - David Dalton, "CNNC Announces Plans For 'Linglong One' SMR", *NucNet*, 23 July 2019, see https://www.nucnet.org/news/cnnc-announces-plans-for-linglong-one-smr-7-2-2019, accessed 26 June 2020.

1071 - Danrong Song, "Opportunities and Challenges in SMR and Its Practice in ACP100", presented at the 17th INPRO Dialogue Forum on Opportunities and Challenges in Small Modular Reactors, 2 July 2019, see https://nucleus.iaea.org/sites/INPRO/df17/IV.1.-DanrongSong-ACP100.pdf, accessed 4 July 2020.

1072 - R. K. Sinha and Anil Kakodkar, "Advanced Heavy Water Reactor", Nu-Power, 1999.

1073 - M. V. Ramana, "The Power of Promise: Examining Nuclear Energy in India", *Penguin India*, 2012.

1074 - K. L. Ramkumar, "Th-LEU Fuel in AHWR to enhance proliferation resistance characteristics", presented at the IAEA 3rd Technical Meeting on Options to incorporate intrinsic proliferation resistance features to Nuclear Power Plants with innovative Small Modular Reactors, 15 August 2011.

1075 - V. K Chaturvedi, "CMD's page", Nu-Power, 2000.

by April 2002; the construction is scheduled to start in April 2004".[1076] Two years later, the construction start was moved to 2005.[1077]

All those projections proved unrealistically premature and a decade later, in 2014, the description of the state of the project from the DAE was still "'we are almost ready' for construction".[1078] Going by a presentation at an IAEA meeting on SMRs in July 2019, the AHWR was entitled an "R&D programme" suggesting that construction is unlikely to start anytime soon.[1079]

RUSSIA

Russia is developing a number of SMR designs. One of these designs, the KLT-40S, is intended for deployment on a barge as a floating nuclear power plant. Two KLT-40S reactors were deployed on the Akademik Lomonosov, connected to the grid in December 2019,[1080] and commissioned in May 2020[1081] (see also Figure 8). The Akademik Lomonosov's construction has taken about four times as long as originally projected; a little before construction of the ship began in 2007, Rosatom announced that the plant would begin to operate in October 2010.[1082] Not surprisingly, it has become more expensive, from an initial estimate of around 6 billion rubles (US$$_{2007}$232 million),[1083] to at least 37 billion rubles as of 2015 (US$$_{2015}$740 million).[1084]

Rosatom is now promoting the RITM series of small PWR-type reactors and does not seem to be prioritizing the KLT-40S design anymore. In a June 2020 presentation to the International Framework for Nuclear Energy Cooperation (IFNEC, formerly Global Nuclear Energy Partnership or GNEP), a Rosatom Marketing Director termed these "the latest development that incorporates all the best features from its predecessors".[1085] The RITM series is not new since it has already been manufactured for icebreaker ships.[1086] However, future variants of this

1076 - B. Bhattacharjee, "'Sanctions act as catalyst': Interview with B. Bhattacharjee, Director, Bhabha Atomic Research Centre", *Frontline*, 24 November 2001.

1077 - B. Bhattacharjee, "An Overview of R&D in Fuel Cycle Activities of AHWR", in Indian Nuclear Society, "Nuclear fuel cycle technologies: closing the fuel cycle", INSAC-2003, 2003.

1078 - Phil Chaffee, "Behind the First AHWR", *Nuclear Intelligence Weekly*, 10 October 2014.

1079 - Alok Chaurey, "R&D Programme in BARC on AHWR-300 Design & Technology Development and Innovative Reactors", presented at the Second Meeting of the Technical Working Group for Small and Medium-sized or Modular Reactor (TWG-SMR), 9 July 2019, see https://nucleus.iaea.org/sites/htgr-kb/twg-smr/SitePages/2019.aspx, accessed 25 June 2020.

1080 - *NIW*, "Russia", *Nuclear Intelligence Weekly*, 20 December 2019.

1081 - Elena Pashina, "Rosatom RITM series SMRs", presented at the IFNEC SMR Webinar Series, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 5 July 2020.

1082 - 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; 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, October 2007.

1083 - *WNN*, "Russian floating reactor construction starts", 17 April 2007, see http://www.world-nuclear-news.org/newsarticle.aspx?id=13250, accessed 30 April 2017.

1084 - 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.

1085 - Elena Pashina, "Rosatom RITM series SMRs", IFNEC, 23 June 2020, op. cit.

1086 - *WNN*, "Russia plans next two nuclear icebreakers", 30 October 2019, see https://www.world-nuclear-news.org/Articles/Russia-plans-next-two-nuclear-icebreakers, accessed 7 July 2020.

series are either land-based (RITM-200N) or having longer periods between refuelings, most likely because of higher enrichment levels for the fuel used.1087

Two other SMR designs by Russian developers that have long been promoted are the lead-bismuth cooled SVBR-100 and the lead cooled BREST-300 fast reactors. It was reported in May that pre-construction activities had commenced at the Siberian Chemical Combine (SCC) in Seversk prior to the eventual construction of a lead-cooled BREST.[1088] This is about four years later than planned: according to the official Federal Target Program (FTP) titled "Nuclear power technologies of the new generation", the construction of a prototype unit of the lead-cooled fast reactor BREST-300 was to have started in 2016.[1089] The reactor is now projected to be completed "before the end of 2026".[1090]

The SVBR-100 lead-bismuth cooled fast reactor development appears to have been "effectively discontinued".[1091] Officially, according to a Government resolution adopted in November 2017 on amending the FTP, the construction of the SVBR-100 has just been postponed beyond the horizon of 2020.[1092] The dubious status of the project is because the reactor is reported to have cost much more than initially estimated—36 billion rubles (US$632 million) as compared to 15 billion rubles.[1093]

SOUTH KOREA

South Korea's System-Integrated Modular Advanced Reactor (SMART), a 100 MW Pressurized Water Reactor, received Standard Design Approval from Korea's Nuclear Safety and Security Commission in July 2012.[1094] Although Korea Atomic Energy Research Institute (KAERI), the developer of the design, was planning "to build a demonstration plant to operate from 2017", there were no orders for "an initial reference unit" in South Korea.[1095]

1087 - Elena Pashina, "Rosatom RITM series SMRs", IFNEC, 23 June 2020, op. cit.; and IAEA, "Advances in Small Modular Reactor Technology Developments: A Supplement to: Advanced Reactors Information System (ARIS) 2018 Edition", 2018.

1088 - *NEI*, "Preparatory construction for Brest-300 reactor begins in Russia", *NEI Magazine*, 22 May 2020, see https://www.neimagazine.com/news/newspreparatory-construction-for-brest-300-reactor-begins-in-russia-7936880, accessed 7 July 2020.

1089 - L. Andreeva-Andrievskaya and Rosatom, "Nuclear R&D Activities in Russia", presented at the NI2050 Workshop, July 2015, see https://www.oecd-nea.org/ndd/workshops/ni2050/presentations/docs/2_20_Russia_Nuclear%20R_D%20Activities%20in%20Russia_L_Andreeva_Andrievskaya,%20ROSATOM.pdf, accessed 29 July 2019.

1090 - *WNN*, "Russia awards contract to build BREST reactor", 5 December 2019, see https://world-nuclear-news.org/Articles/Russia-awards-contract-to-build-BREST-reactor, accessed 7 July 2020.

1091 - Anatoli Diakov and Pavel Podvig, "Construction of Russia's BN-1200 fast-neutron reactor delayed until 2030s", IPFM Blog, 20 August 2019, see http://fissilematerials.org/blog/2019/08/the_construction_of_the_b.html, accessed 7 July 2020.

1092 - Government of the Russian Federation, "О внесении изменений в федеральную целевую программу 'Ядерные энерготехнологии нового поколения на период 2010-2015 годов и на перспективу до 2020 года' (утратило силу с 01.01.2019 на основании постановления Правительства Российской Федерации от 30.11.2018 N 1451), Постановление Правительства РФ от 11 ноября 2017 года №1367", 11 November 2017, see http://docs.cntd.ru/document/555631831, accessed 30 July 2019. Thanks to Anatoli Diakov for this reference and information.

1093 - *NEI*, "Russia seeks partners for its SVBR project", 15 November 2016, see http://www.neimagazine.com/news/newsrussia-seeks-partners-for-its-svbr-project-5669556, accessed 30 April 2017.

1094 - Kwon Dong-joon, "Korean All-in-one SMR Won World's First Standard Design Approval", *etnews*, 5 July 2012, see http://english.etnews.com/20120705200008, accessed 30 April 2017.

1095 - *WNN*, "Korea, Saudi Arabia progress with SMART collaboration", 7 January 2020, see https://www.world-nuclear-news.org/Articles/Korea-Saudi-Arabia-progress-with-SMART-collaborati, accessed 4 July 2020.

As a result, KAERI has been pursuing export orders, especially with Saudi Arabia. (The SMART is also one of eight SMR designs under consideration in Jordan.[1096]) In 2015, KAERI signed a Memorandum of Understanding (MoU) with the King Abdullah City for Atomic and Renewable Energy (KA-CARE), to "conduct a three-year preliminary study to review the feasibility of constructing SMART reactors in Saudi Arabia".[1097] That study ended by focusing on what it called Pre Project Engineering (PPE), including developing a First Of A Kind (FOAK) design and training Saudi engineers; a SMART PPE package was delivered to KA-CARE at the end of February 2019.[1098] In January 2020, the agreement was updated to create a joint venture, that is "to complete the design of the reactor and non-nuclear infrastructure to support it", and "seek a license to build the unit in Saudi Arabia and to offer it for export".[1099] KA-CARE has also advanced ambitious if unrealistic plans of localizing some of the reactor manufacture in Saudi Arabia.[1100]

UNITED KINGDOM

In 2014, the U.K. Government and a consortium of nuclear industry organizations commissioned a feasibility study for SMRs that was carried out by the National Nuclear Laboratory (NNL).[1101] That study "considered four designs in detail": ACP100+ (designed by China National Nuclear Corporation – CNNC); mPower (B&W and Bechtel); Westinghouse SMR (Westinghouse); and NuScale (Fluor). Of these, two designs, mPower and Westinghouse SMR, are no longer being pursued.

The following year the U.K. Government announced that "at least £250 million" (US$$_{2015}$380 million) will be spent by 2020 on an "ambitious" program to "position the UK as a globa leader in innovative nuclear technologies" and that there would "be a competition" to identify the best SMR and aim to build "one of the world's first SMRs in the UK in the 2020s".[1102]

It might be somewhat surprising that since then the SMR design selected for the provision of Government funding is not one of the four designs that were considered in the 2014 study, but a design by Rolls Royce that is still in an early stage of development. In November 2019, the Government announced that it would provide "match funding" of up to £18 million (US$22.7 million) to a "consortium of companies" whose most prominent member is Rolls-

1096 - Kamal Araj, "Jordan's Nuclear Power Perspective for SMR Deployment", presented at the IFNEC SMR Webinar Series, 2 June 2020, see https://www.ifnec.org/ifnec/jcms/g_13206/ifnec-smr-webinar-series-june-2020, accessed 5 July 2020.

1097 - *WNN*, "Saudi Arabia teams up with Korea on SMART", 4 March 2015, see http://world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html.

1098 - Joo Hyung Moon, "SMART PPE Achievements", presented at the 17th INPRO Dialogue Forum on Opportunities and Challenges in Small Modular Reactors, 2 July 2019, see https://nucleus.iaea.org/sites/INPRO/df17/IV.3-JooHyoungMoon.pdf, accessed 4 July 2020.

1099 - Dan Yurman, "South Korea's SMART SMR Gets New Life", *Neutron Bytes*, 18 January 2020, see https://neutronbytes.com/2020/01/18/south-koreas-smart-smr-gets-new-life/, accessed 4 July 2020.

1100 - Ali Ahmad, Reem Salameh and M. V. Ramana, "Localizing Nuclear Capacity? Small Modular Reactors and Saudi Arabia", Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, July 2019, see www.aub.edu.lb/ifi.

1101 - *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.

1102 - Damian Carrington, "George Osborne puts UK at the heart of global race for mini-nuclear reactors", *The Guardian*, 24 November 2015, see https://www.theguardian.com/environment/2015/nov/24/mini-nuclear-reactors-answer-to-climate-change-crisis, accessed 6 July 2019.

Royce.[1103] This figure is much lower than the figure of over £200 million (US$252 million) that Rolls Royce reportedly demanded of the Government in 2019.[1104] That figure went up to £250 million (US$315 million) in 2020 in proposals reportedly submitted to Ministers in the U.K. to construct factories to build these SMRs "by next year".[1105]

Although Rolls Royce has been talking about small reactors since the 1970s,[1106] the SMR design favored by Rolls Royce does not really fit the usual definition of an SMR because its output is 440 MW.[1107] The IAEA's Advanced Reactors Information System terms this a "mature concept" but it is not clear how well developed it really is. The U.K. Office for Nuclear Regulation states on its Generic Design Assessment webpage that as of 25 February 2020, when it was last updated, that it is "currently assessing one reactor design: General Nuclear System's UK HPR1000" (or the Hualong).[1108] It is not clear how Rolls Royce seeks to start building a manufacturing plant, when it has not even submitted a reactor design for regulatory review.

UNITED STATES

The United States continues to actively pursue SMRs and the Department of Energy (DOE) invested hundreds of millions of dollars into promoting research and development work on SMRs over the past decade. The main funding program was established in 2012 in the form of a cost-share funding opportunity to cover expenses associated with research and development, design certification, and licensing. One of the designs that received DOE funding through this program, the NuScale design, is currently the one that can be said to be closest to deployment in the U.S., because it has submitted the first design certification application for an SMR of this class to the NRC.

NuScale has received US$226 million from the DOE through the 2012 program, and in 2018, DOE provided another grant of US$40 million to NuScale.[1109] In February 2020, the DOE reportedly "agreed to spend up to US$350 million in new matching funds".[1110]In the "initial project baseline" DOE would spend US$263 million over the next five years and NuScale would have to match these funds. However, the agreement also envisions the possibility of the project cost escalating "to a ceiling of US$700 million, with overruns to be split on a 50-50 basis".

The rest of the funding for NuScale comes from its parent company, the Fluor Corp. In March 2020, the Chairman and Chief Executive Officer of NuScale Power told the House Committee

1103 - *WNN*, "UK confirms funding for Rolls-Royce SMR", 7 November 2019, see https://world-nuclear-news.org/Articles/UK-confirms-funding-for-Rolls-Royce-SMR, accessed 7 July 2020.

1104 - Sylvia Pfeifer and David Sheppard, "Rolls-Royce leads drive for small nuclear sites: Energy", *Financial Times*, 28 January 2019.

1105 - Neil Craven, "Rolls-Royce triggers £250bn nuclear mini reactor race: Huge boost for economy if UK consortium gets go-ahead to build fleet of mini reactor plants", *Financial Mail on Sunday*, as published on *This is Money*, 13 June 2020, see https://www.thisismoney.co.uk/money/news/article-8417289/Rolls-Royce-triggers-250bn-nuclear-mini-reactor-race.html, accessed 16 June 2020.

1106 - C.D. Heising-Goodman, "Supply of appropriate nuclear technology for the developing world: Small power reactors for electricity generation", Applied Energy, 1981.

1107 - Martin J. Goodfellow, "Rolls Royce consortium SMR", presented at the IFNEC SMR Webinar Series, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 5 July 2020.

1108 - ONR, "Generic Design Assessement (GDA)", Office for Nuclear Regulation, 25 February 2020, see http://www.onr.org.uk/civil-nuclear-reactors/generic-design-assessment.htm, accessed 7 July 2020.

1109 - Pete Danko, "Oregon's small-nuke company wins $40M federal grant", *Portland Business Journal*, 27 April 2018, see https://www.bizjournals.com/portland/news/2018/04/27/oregon-small-nuke-company-nuscale-wins-40m-federal.html, accessed 28 June 2019.

1110 - Phil Chaffee, "DOE Agrees Major New Commitment to NuScale", *Nuclear Intelligence Weekly*, 21 February 2020.

on Energy and Commerce that "Fluor and its investors contributed $643 million, or 67% of expenditures to date, and the Federal Government has contributed $314 million" to make up a total of US$957 million.[1111] In all, there would have been an investment of at least US$1.5 billion into NuScale before it can receive design certification from the NRC, a necessary step for a NuScale unit to be deployed.

The expected date for certification has been continually pushed back. NuScale officials announced in 2008 that NuScale Power has "advised the US Nuclear Regulatory Commission of its intent to initiate preapplication reviews with a view towards submitting an application for design certification in 2010. The first preapplication meeting was held on 24 July 2008… With timely application for a combined construction and operating licence (COL), a NuScale plant could be producing electricity by 2015-16".[1112] In a October 2008 talk, an NRC official projected that NuScale would submit an application for design certification in early 2010 and that review would be completed by early 2015.[1113]

In 2010, SNL Energy's *Power Daily* reported that NuScale intended "to submit a design certification application to the NRC early in 2012" and was hoping "to have its first reactor online in 2018".[1114] The NRC even issued a notice in the Federal Registry that said "NuScale Power, Inc. (NuScale) has submitted a letter of intent to the U.S. Nuclear Regulatory Commission (NRC) for a design certification application in 2012".[1115] The following year, the OECD's Nuclear Energy Agency report on SMRs projected that NuScale would file a licensing application in 2011 and had a targeted deployment date of 2018 for a FOAK (First Of A Kind) plant.[1116] NuScale finally submitted its design for review only on the last day of 2016.

Over the past year, it has become clear that the road ahead will not be smooth. In March 2020, the NRC's Advisory Committee on Reactor Safeguards (ACRS) issued a letter warning that the "design and performance of the steam generators have not yet been sufficiently validated".[1117] The Advisory Committee pointed out that the present design of the steam generators "introduces different failure modes" resulting in their "design and performance" not being sufficiently validated. There are two concerns, one having to do with instability and the other with corrosion, due to "accelerated wear of the alloy 690TT steam generator tubing material".[1118] The NRC has concurred with the ACRS findings and its staff have said that further analysis or testing results to "demonstrate the design and performance of the steam

1111 - John L. Hopkins, "Building a 100 Percent Clean Economy: Advanced Nuclear Technology's Role in a Decarbonized Future", presented at the House Committee on Energy and Commerce Subcommittee on Energy, 3 March 2020, see https://docs.house.gov/meetings/IF/IF03/20200303/110640/HHRG-116-IF03-Wstate-HopkinsJ-20200303.pdf, accessed 23 June 2020.

1112 - Paul Lorenzini and Jose N. Reyes, "Power Plant Design - Compact and bijou: a new approach to design", *Nuclear Engineering International*, 2 October 2008.

1113 - Edward Baker, "NRC's Advanced Reactor Program", NRC, 16 October 2008.

1114 - Wayne Barbe, "NuScale sees large upside in small nuclear units", *SNL Energy Power Daily*, 30 June 2010.

1115 - NRC, "Nuclear Regulatory Commission: Notices: In the Matter of NuScale Power, Inc. and All Other Persons; Who Seek or Obtain Access to Safeguards Information Described Herein; Order Imposing Safeguards Information Protection Requirements for Access to Safeguards Information (Effective Immediately): [FR DOC # 2010-15730]", Federal Register, 29 June 2010.

1116 - NEA, "Current Status, Technical Feasibility, and Economics of Small Nuclear Reactors", Nuclear Energy Agency, OECD, 2011.

1117 - Advisory Committee on Reactor Safeguards, "NuScale Area of Focus - Helical Tube Steam Generator Design", 2020, see https://www.nrc.gov/docs/ML2009/ML20091G387.pdf, accessed 19 April 2020.

1118 - Jessica Sondgeroth, "A Pox on NuScale's SMR Design Certification", *NIW*, 15 May 2020.

generators" will have to be included as part of the application for the license to construct and operate the reactor.[1119]

NuScale has also increased the power rating per module from 50 MW to 60 MW and this will cause further delays. A NRC spokesperson clarified, "NuScale must apply separately for the uprate" and that the current schedule only applies to the 50 MW design.[1120] The changes in the reactor design will have to be evaluated by NRC and that could result in NRC requiring changes in the NuScale design to address potential vulnerabilities.

Another source of potential delays are the financial troubles of Fluor Corporation. Stock prices have declined from roughly US$60 in October 2018 to roughly US$12 in early July 2020.[1121] It is being investigated by the Securities and Exchange Commission and the Justice Department has subpoenaed documents concerning a fixed-price federal project.[1122] In May 2019, a senior Credit Suisse analyst wrote to investors that there was "opportunity for positive change at Fluor" but went on to suggesting that the firm could reduce "underperforming investments," including its NuScale SMR startup "which is long overdue, in our opinion".[1123]

Amidst all this, NuScale is trying to effect its first construction with commitment for the electricity to be purchased by Utah Associated Municipal Power Systems (UAMPS), but, as of June 2020, it has not received sufficient orders from members of UAMPS to absorb all the electrical output of a NuScale power plant, which consists of 12 units with gross outputs of 60 MW each.

NuScale claims that the levelized cost of energy from the UAMPS project would be around US$65/MWh, largely because of favorable financing that might be available for this project.[1124] But, if one goes by the history of cost overruns at nuclear projects, this figure is unlikely to materialize, and the levelized cost of generation might be as high as US$86 to US$104/MWh, depending on the assumptions.[1125] Even if one goes with NuScale's claim about electricity costing up to US$65/MWh, there are many other alternatives at lower cost[1126] (see also Nuclear Power vs. Renewable Energy Deployment).

A more recent focus for SMR vendors has been the U.S. Department of Defense. There is a growing set of reports extolling the advantages of microreactors for military bases. The American Security Project, for example, called for micro reactors to "be fueled with…high-

1119 - Michael McAuliffe, "NRC raises questions about NuScale design, delays interim review milestone", *NW*, 7 May 2020.

1120 - Stephanie Cooke, "US Nuclear's Last Hope Hits Snags", *NIW*, 26 July 2019.

1121 - *Yahoo Finance*, "Fluor Corporation (FLR)", 17 April 2020.

1122 - Paul O'Donnell, "Fluor faces Justice Department subpoena over costs for Army project", *Dallas News*, 8 May 2020, see https://www.dallasnews.com/business/local-companies/2020/05/08/fluor-faces-justice-department-subpoena-over-us-army-project-costs/, accessed 10 May 2020; and Tomi Kilgore, "Fluor's stock drops after disclosing investigation by regulators over charges recorded", *MarketWatch*, 8 May 2020, see https://www.marketwatch.com/story/fluors-stock-drops-after-disclosing-investigation-by-regulators-over-charges-recorded-2020-05-08, accessed 9 May 2020.

1123 - Debra K Robin, "Fluor Continues Management Shakeout to Boost Results", *Engineering News-Record*, 30 May 2019, see https://www.enr.com/articles/46979-fluor-continues-management-shakeout, accessed 21 September 2019.

1124 - Stephanie Cooke, "NuScale Prepares for SMR Development Phase", *NIW*, 29 March 2019.

1125 - 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.

1126 - Energy Strategies, "Analyzing the Cost of Small Modular Nuclear Reactors and Alternate Power Portfolios", Healthy Environment Alliance of Utah, May 2019, see https://www.healutah.org/smnr/, accessed 28 June 2019.

assay low-enriched uranium fuel [that] would be enriched to between 5% and 20% of U-235", which is higher than the fuel used in commercial nuclear plants.[1127]

While all this talk about using SMRs someday to power military bases is going on, renewables are becoming a real source of energy in many bases already. The U.S. state of New Jersey's biggest 28.5 MW solar project is actually on a naval base, which was built as "part of the Navy's energy resiliency initiative" and became operational in May 2020.[1128] Although connected to the local utility grid, reports suggest that it is designed to also direct all power locally to the base itself in the event of an emergency, making it "islandable".[1129]

CONCLUSION

While talk about SMRs continues unabated, there is growing evidence that the trends that have largely diminished prospects for large nuclear plants—delays, poor economics, and the increased availability of low-carbon alternatives at rapidly decreasing cost—plague these technologies as well, and there is no need to wait with bated breath for SMRs to be deployed.

1127 - Andrew Holland, "Micro Nuclear Reactors: Prospects for Deploying Land-Based Nuclear Energy for the US Military", American Security Project, October 2019, see https://www.americansecurityproject.org/perspective-micro-nuclear-reactors/, accessed 6 June 2020.

1128 - Linda Lindner, "CS Energy completes construction of New Jersey's largest solar project", *NJBIZ*, 18 May 2020, see https://njbiz.com/cs-energy-completes-construction-new-jerseys-largest-solar-project/, accessed 6 June 2020.

1129 - Michelle Lewis, "New Jersey's largest solar farm has been completed", Electrek, 18 May 2020, see https://electrek.co/2020/05/18/new-jersey-largest-solar-plant-completed/, accessed 6 June 2020.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

INTRODUCTION

As with other divisions in the economy, the impact of measures to contain the COVID-19 pandemic will be significant in the power sector in the short, medium, and probably long term.

The IEA expected in April 2020[1130] that global power demand would fall by 5 percent in 2020, eight times more than in the 2009 financial crisis, but this was revised in June to a 6 percent drop.[1131] However, the impact is likely to be far greater in some regions. This is highlighted by the significant decline that has been seen in some countries where daily electricity demand decreased by at least 15 percent in France, India, Italy, Spain, the U.K. and large parts of the U.S.[1132]

Despite falling demand, the contribution and actual volume of generation of power from renewables has been growing in 2020. In Q1, global renewable electricity production increased 3 percent mainly because of a double-digit percentage increase for wind power and a jump in solar photovoltaic (PV) output from projects installed over the previous year. The share of renewables in global electricity supply, including hydro, reached 27.5 percent in Q1 2020, up from 26 percent in Q1 2019. On the other hand, nuclear power generation fell by 3 percent year-on-year in Q1 2020 in response to lower demand and because fewer reactors were operational in some regions.[1133]

Falling demand in power markets has resulted in lower prices. In Europe, the most significant year-on-year decline was seen in the Nord Pool market, with a plunge of 78 percent, with the average price being €9/MWh during March 2020, while the smallest decline was seen in Germany with a fall of still 27 percent, to €22.5/MWh.[1134] In Japan, the day-ahead prices on the Japan Electric Power Exchange (JEPX) were 0.01 yen (US$0.0001 or US$c0.01) per kilowatt hour (kWh) for the first time in February 2020[1135]—virtually free electricity.

The medium-term impact of the pandemic on the power mix is far from clear. Falling power demand and prices are likely to reduce the economic imperative to invest in new capacity, and therefore the extent to which new power plants are built may to a large degree depend on governmental stimulus packages. The IEA has called on the Governments, "when designing

1130 - IEA, "Global Energy Review 2020", International Energy Agency, April 2020, see https://www.iea.org/data-and-statistics, accessed 13 June 2020.

1131 - IEA, "Sustainable Recovery - World Energy Outlook Special Report", June 2020, see https://www.iea.org/reports/sustainable-recovery, accessed 20 June 2020

1132 - IEA, "Global Energy Review 2020", April 2020, op. cit.

1133 - IEA, "Global Energy Review 2020", April 2020, op. cit.

1134 - AleaSoft Energy Forecasting, "Fall in electricity markets prices in march due to the coronavirus crisis", 2 April 2020, see https://aleasoft.com/fall-electricity-markets-prices-march-coronavirus-crisis/, accessed 13 June 2020.

1135 - *Financial Tribune*, "Japan Power Prices Hit Zero as Coronavirus Hammers Industries", 13 May 2020, see https://financialtribune.com/articles/energy/103347/japan-power-prices-hit-zero-as-coronavirus-hammers-industries, accessed 13 June 2020.

these packages, governments should bear in mind the structural benefits that renewables can bring in terms of economic development and job creation while also reducing emissions and fostering technology innovation".[1136]

"The financial weakness of the electricity sector is likely to shift investment away from nuclear power"

While there is undoubtedly greater support for renewable energy, the same cannot be said for nuclear power and the prospects for the atom have worsened. Laszlo Varro, the Chief Economist of the IEA, notes that:

> The financial weakness of the electricity sector is likely to shift investment away from nuclear power. There are indications that even utilities that have already made the necessary investments in safety measures and secured approvals for lifetime extensions could shut down their nuclear plants prematurely for financial reasons. A mothballed gas turbine can be restarted fairly easily, but the shutdown of a nuclear plant is usually final.[1137]

Therefore, the impact of the pandemic could lead to a slowdown of investment in the power sector generally, with renewables affected the least. However, it is also possible that the stimulus program will be used as a means not only to create employment but to advance decarbonization objectives. As and when this occurs it would be important for policy makers and financiers to look to recent trends, as described below, and take note of the extent to which renewable energy is outperforming nuclear power as a mitigation tool.

INVESTMENT

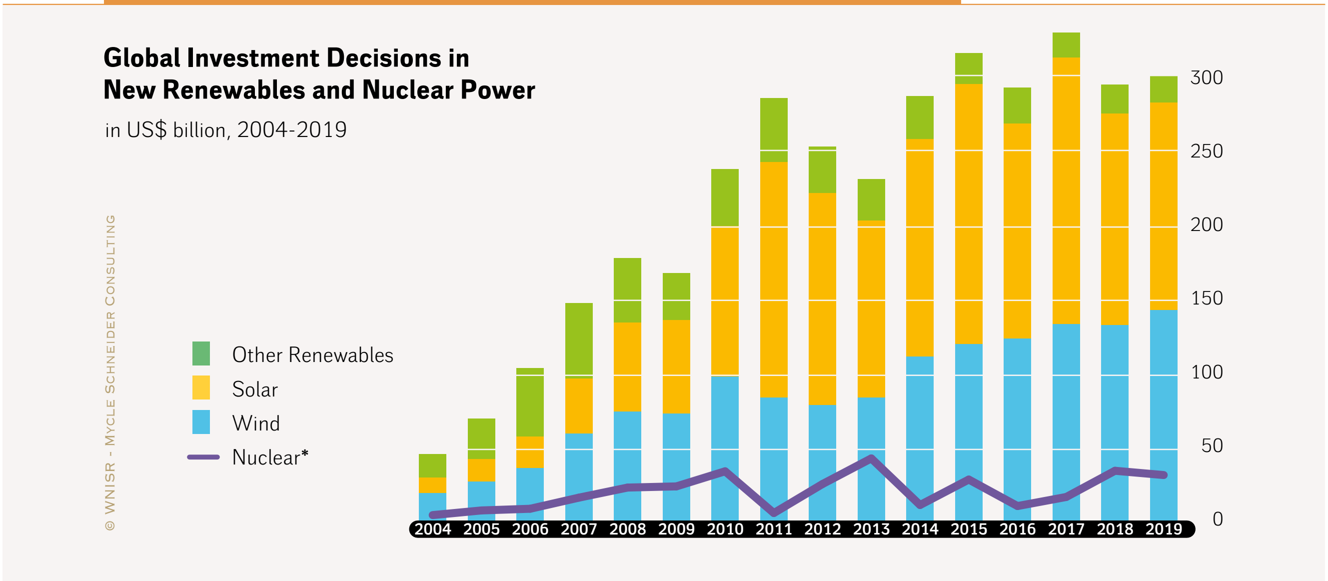
Figure 48 compares the annual investment decisions for the construction of new nuclear plants with those for renewable energy since 2004. Construction began on five nuclear reactors in 2019, two in China (possibly two more, but there is no official confirmation, see Construction Starts; those are not included in Figure 48 and Figure 49) and one each in Iran, Russia, and the U.K. this is the same as in 2018, four new reactors in 2017, three in 2016, and eight new projects in 2015. The total reported investment for the construction of the 2019-projects is around US$31 billion for 5.8 GW. However, this is still less than a quarter of the investment in wind or in solar individually, with over US$138 billion investment in wind power and US$131 billion in solar.

Globally, the relative importance of Europe and North America for renewable energy investments continues to diminish, with the rise of Asia, especially China (see Figure 51). Chinese nominal-dollar renewable investment rose from US$26 billion in 2008 to US$135 billion in 2017 before a steep cut to US$91 billion in 2018 and $83 billion in 2019. Total *cumulated* investment in nuclear in China over the same period was about US$90 billion (not including two CAP1400 reactors, whose construction start has not been confirmed yet).

1136 - Heymi Bahar, "The coronavirus pandemic could derail renewable energy's progress. Governments can help.", IEA, 4 April 2020, see https://www.iea.org/commentaries/the-coronavirus-pandemic-could-derail-renewable-energy-s-progress-governments-can-help, accessed 13 June 2020.

1137 - Laszlo Varro and Peter Fraser, "The Covid-19 crisis is undermining nuclear power's important role in clean energy transitions", IEA, 12 June 2020, see https://www.iea.org/commentaries/the-covid-19-crisis-is-undermining-nuclear-power-s-important-role-in-clean-energy-transitions, accessed 13 June 2020.

Figure 48 · Global Investment Decisions in Renewables and Nuclear Power 2004–2019



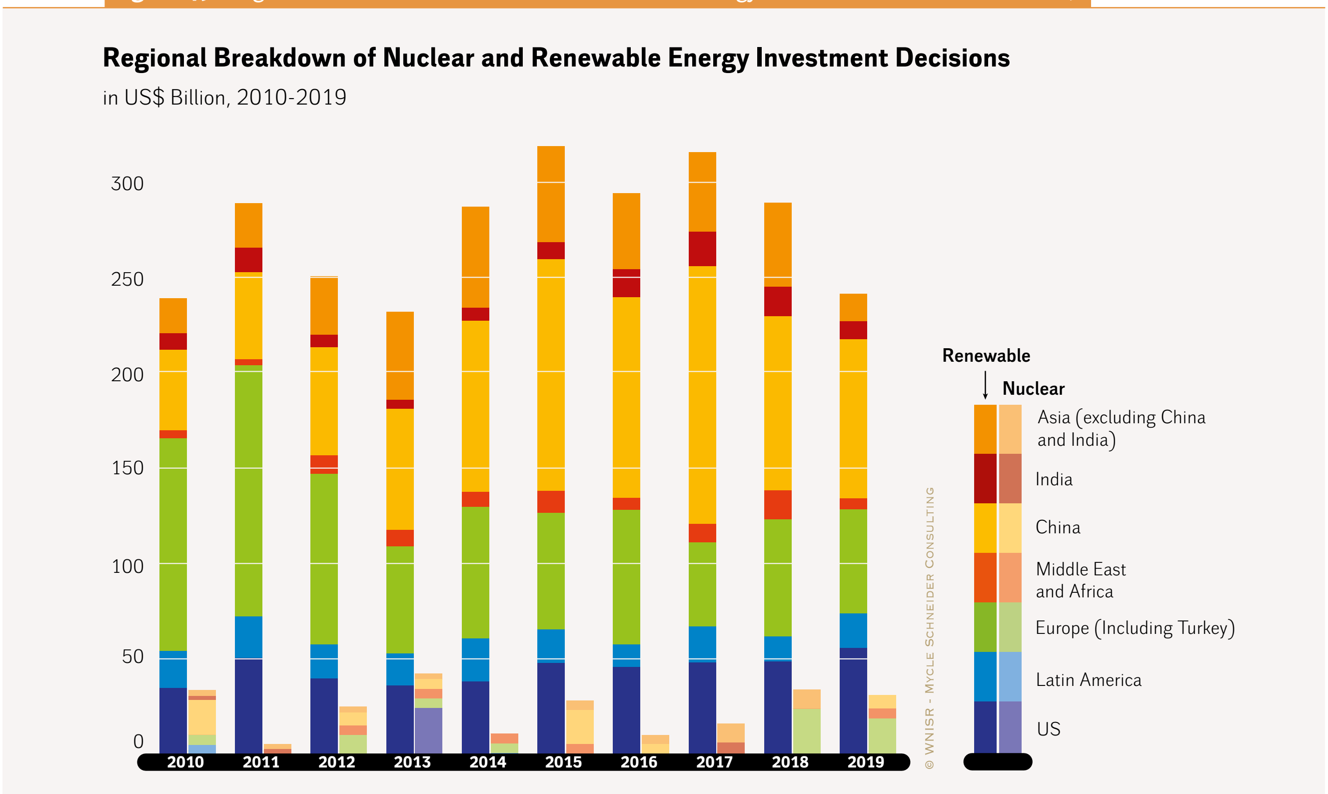
Sources: FS-UNEP/BNEF 2018, 2020, REN21 2019 and WNISR Original Research, 2020

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.

In addition, this graph does not show investments for two reactors in China—two CAP1400 Rongcheng/Shidaowan—whose construction start in 2019 has not been officially confirmed.

Figure 49 · Regional Breakdown of Nuclear and Renewable Energy Investment Decisions 2010–2019



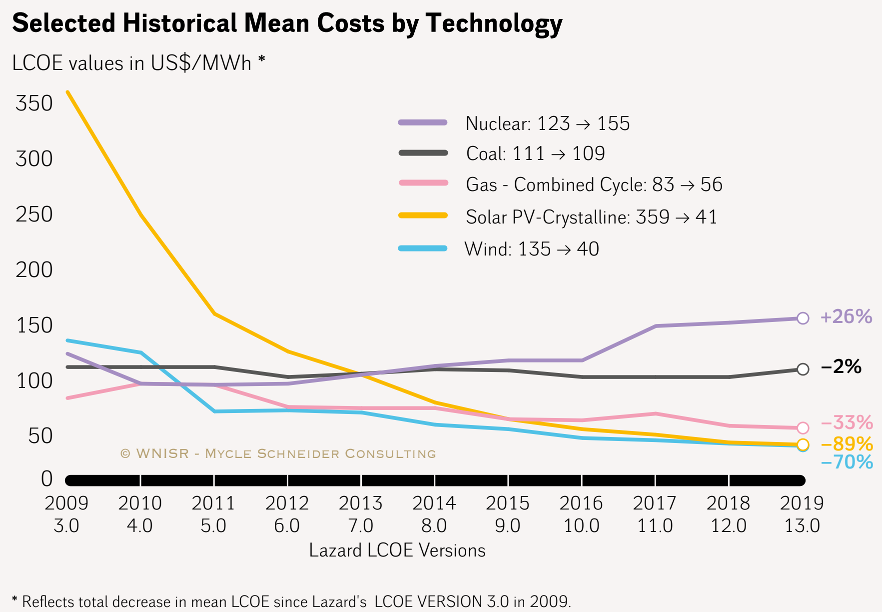
Sources: BNEF/UNEP 2020, WNISR Original Analysis, 2020

Notes: This graph does not show investments for two reactors in China
—two CAP1400 Rongcheng/Shidaowan—whose construction start in 2019 has not been officially confirmed.

TECHNOLOGY COSTS

The annual levelized Cost of Energy (LCOE) analysis for the U.S. undertaken by Lazard at the end of 2019 (see Figure 50), suggests that the cost of solar PV (crystalline, utility-scale) averages US$40/MWh, compared to US$65 in 2015; onshore wind is US$41/MWh compared to US$55/MWh in 2015 and nuclear is US$155 (US$117 in 2015). Over the last five years, the LCOE of nuclear has risen by over 50 percent, while renewables have now become the cheapest of any type of power generation. What is remarkable about these trends is that the costs of renewables continue to fall due to incremental manufacturing and installation improvements, while nuclear, despite over half a century of industrial experience, continue to see costs rising. Nuclear power is now the most expensive form of generation, except for gas peaking plants.[1138]

Figure 50 · The Declining Costs of Renewables vs. Traditional Power Sources



Source: Lazard Estimates, 2019[1139]

Notes

LCOE=Levelized Cost of Energy.
This graph reflects average of unsubsidized high and low LCOE range for given version of LCOE study.
It primarily relates to North American renewable energy landscape, but reflects broader/global cost declines.

According to an International Renewable Energy Agency (IRENA) estimate, the global weighted *average* LCOE of utility-scale PV plants fell 13 percent year on year in 2019, leading to a worldwide average of US$68/MWh. The cost of onshore wind declined by 9 percent to US$53/MWh and offshore reached a new low of US$115/MWh, still according to IRENA.[1140] The IEA stated in June 2020 on global costs:[1141]

1138 - Lazards, "Lazard's Levelized Cost of Energy Analysis—Version 13.0", November 2019.

1139 - Lazards, "Lazard's Levelized Cost of Energy Analysis—Version 13.0", November 2019.

1140 - IRENA, "Renewable Capacity Statistics 2019", March 2019, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf, accessed 3 April 2019.

1141 - IEA, "Sustainable Recovery - World Energy Outlook Special Report", June 2020, op. cit.

> Falling costs for new solar PV and wind projects over the past decade have made capital investment far more productive. The expected annual generation from investment in solar PV in 2020 is more than seven-times the amount for the same investment in 2010: for onshore wind it has nearly doubled and for offshore wind it has risen by over 60 percent.

Further declines in the costs of renewables are likely, in particular for offshore wind, as experience continues to lead to costs already significantly below that of the global averages estimated by IRENA; for example in Denmark and the Netherlands costs have fallen to the range of US$53-64/MWh (excl. transmission). Furthermore, Bloomberg New Energy Finance (BNEF) estimated in October 2019 that the global average LCOE for offshore wind was then US$78/MWh.[1142]

As Lazard shows for the U.S., the declining costs of renewables globally contrast with nuclear costs that are at best constant, and more often, when numbers are available, are rising, often significantly. As a consequence, it is now widely recognized that the cost of renewables is now significantly below that of either nuclear power or gas. The IEA stated in their 2019-assessment of nuclear power that

> the high capital cost of nuclear makes it significantly more costly on a levelized costs basis than wind power or gas fired generation in both the European Union and United States.[1143]

INSTALLED CAPACITY AND ELECTRICITY GENERATION

While there has been a slowdown in the rate of increase of investment in renewables, this reflects changes in policies in some countries and regions. Despite this, the rapid reduction in investment costs per MW mean that there is still a rise in the net annual increase in installed capacity. In total, a record 184 GW of new-renewable energy capacity (excluding hydro) was installed in 2019, according to the Renewable Energy Policy Network for the 21st Century (REN21), 20 GW more than the previous year.[1144]

After a slowdown in the past three years, the net capacity addition of wind power has increased with 59.2 GW of new installations in 2019, but still slightly lower than that installed in 2015. Solar PV increased with 97.6 GW to a global record, similar to the 97.4 GW of added capacity in 2018.

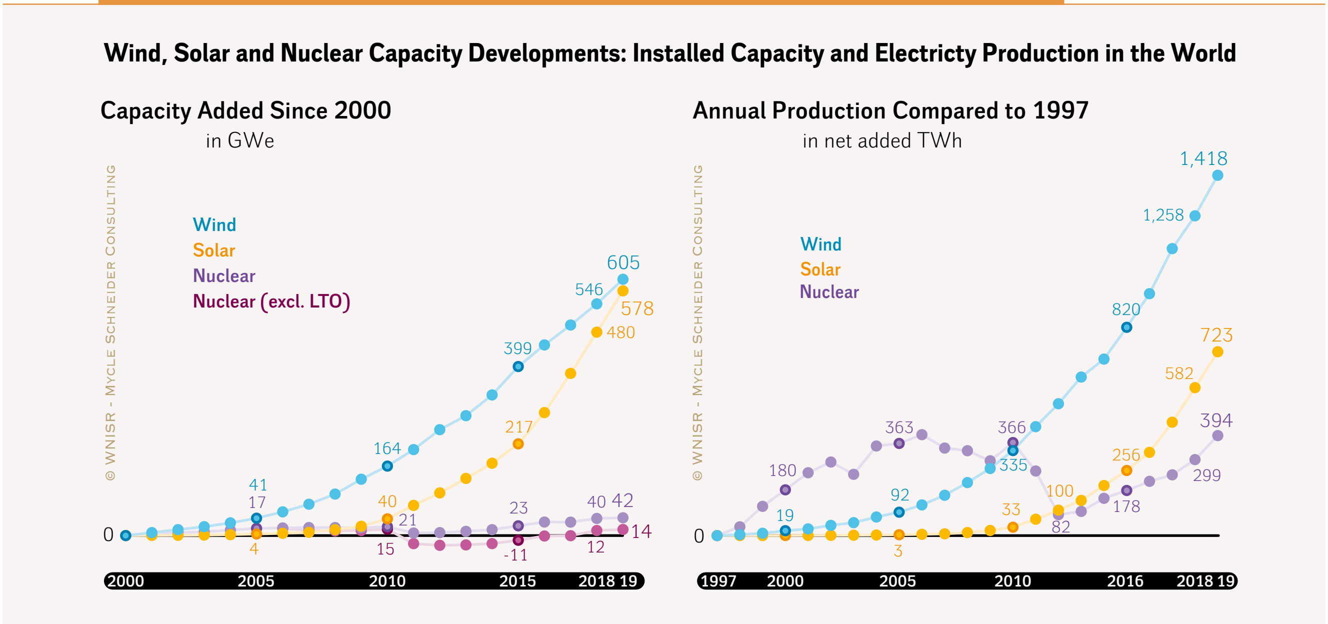
Figure 51 illustrates the extent to which renewables have been deployed at scale since the start of the millennium, an increase in capacity of 605 GW for wind and of 578 GW for solar according to IRENA, compared to the relative stagnation of nuclear power capacity, which over this period increased by around 42 GW, including all reactors currently in LTO. Considering that around 27.5 GW of nuclear power were in LTO as of the end of 2019, and thus not operating, the balance is an addition of 14.5 GW compared to 2000.

1142 - *Renews.biz*, "Offshore wind costs 'drop 32%'", *reNEWS - Renewable Energy News*, 28 October 2019, see https://renews.biz/56081/offshore-wind-costs-drop-32/, accessed 5 July 2020.

1143 - IEA, "Nuclear Power in a Clean Energy System", May 2019, see https://webstore.iea.org/download/direct/2779?fileName=Nuclear_Power_in_a_Clean_Energy_System.pdf, accessed 23 June 2019.

1144 - Frankfurt School of Finance & Management, FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and BloombergNEF, "Global Trends in Renewable Energy Investment in 2020", June 2020, see https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf, accessed 20 June 2020.

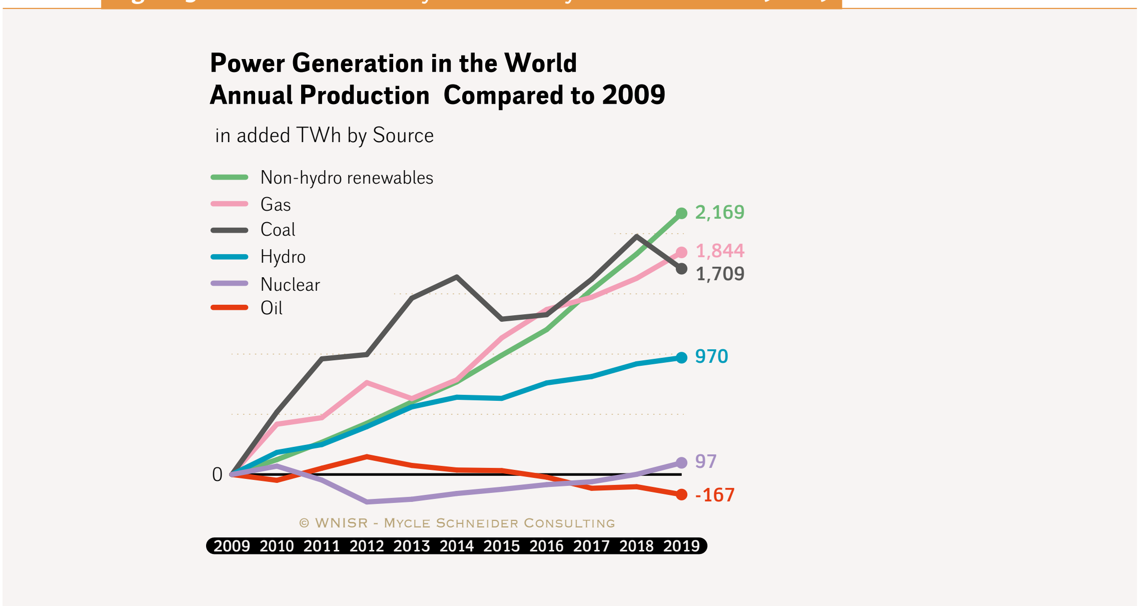
Figure 51 · Variation of Wind, Solar and Nuclear Capacity and Electricity Production in the World



Sources: WNISR, IAEA-PRIS, IRENA, BP Statistical Review, 2020

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 MW of installed capacity than renewables. However, as can be seen in Figure 53, compared to 2000, there has been an additional 1,500 TWh of wind power in 2019, over 720 TWh more electricity from solar PV, compared to an additional 215 TWh of nuclear energy.

Figure 52 · Net Added Electricity Generation by Power Source 2009–2019



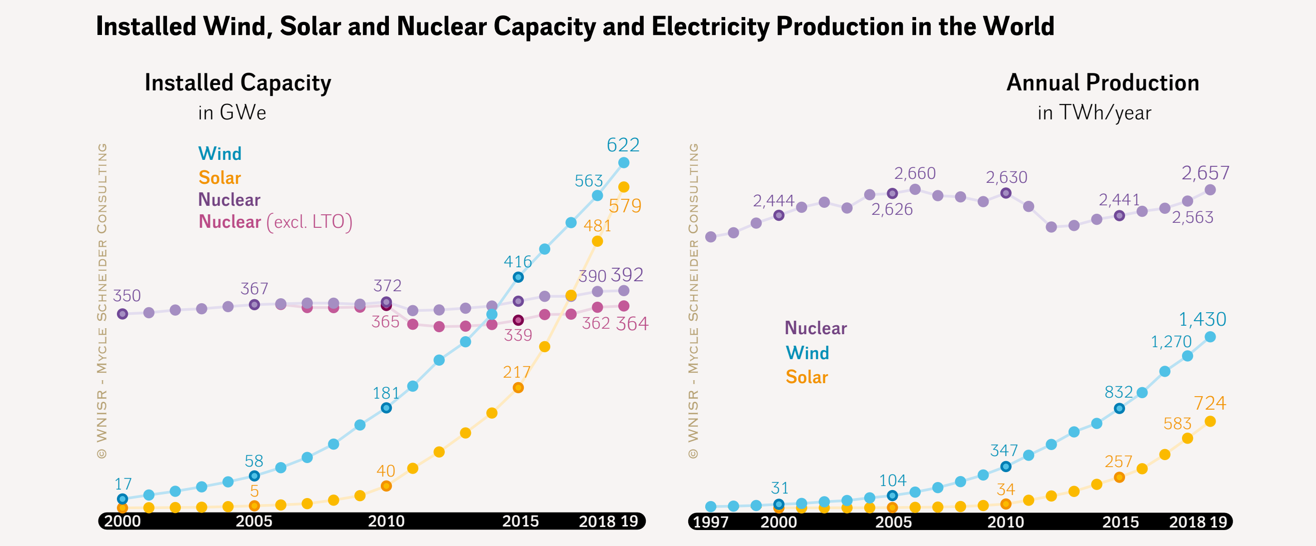
Source: BP Statistical Review, 2020

In 2019, annual global growth rates for the generation from wind power were 12.6 percent (11.3 percent in 2018), 24.3 percent (30.4 percent in 2018) for solar PV, and 3.7 percent (2.4 percent in 2018) for nuclear power.

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 52 hows the extent to which, over the last decade, different energy sources have increased their electricity production. The energy source that has added the greatest amount of electricity over the past decade is non-hydro renewables, generating an additional 2,169 TWh of power. The power sector with the second largest growth was natural gas, followed by coal, hydro and nuclear, while oil's net production remains below its 2009 level.

Due to the stagnation of nuclear power's development, it has been overtaken by wind and solar in total installed generating capacity. And while in 2019, nuclear generated more electricity (2,657 TWh) than the previous year, wind (1,430 TWh) and solar (724 TWh) continue catching up fast, and together now represent 81 percent of nuclear power production (see Figure 53).

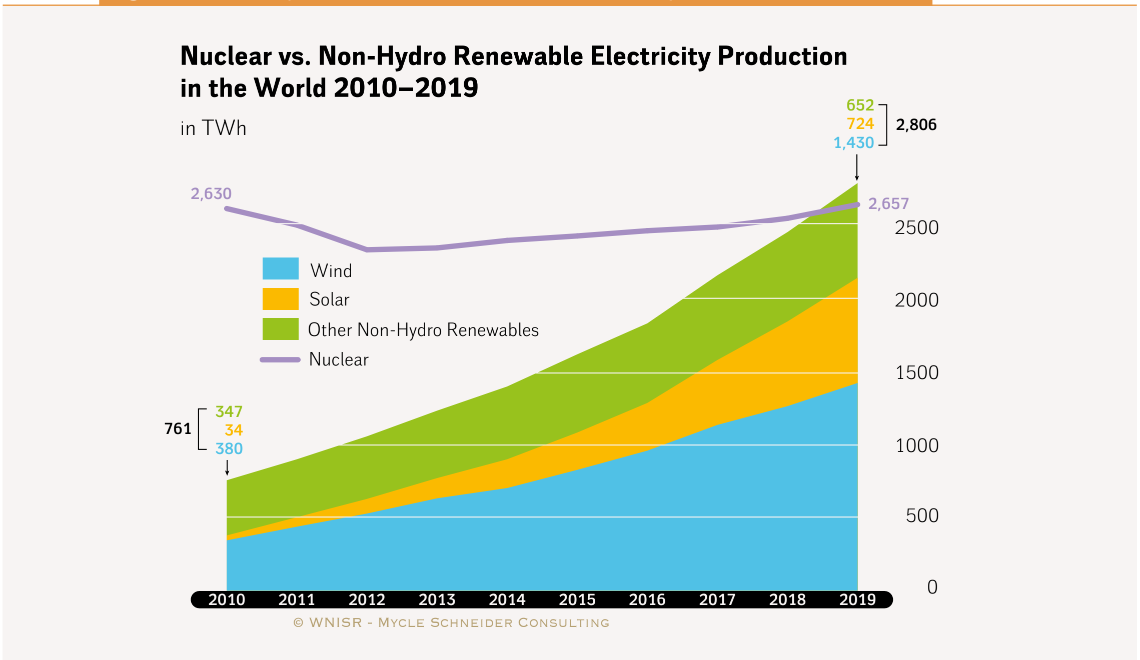
Figure 53 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in the World



Sources: WNISR, IAEA-PRIS, IRENA, BP Statistical Review, 2020

In 2019, for the first time the generation of non-hydro renewables, wind, solar, biomass and other non-hydro renewables like geothermal, exceeded the electricity generation of nuclear power (see Figure 54). While non-hydro renewables increased by a factor of 3.7 over the past decade and generated 2,808 TWh (gross), nuclear power just caught up to pre-Fukushima levels to reach 2,657 TWh (net) or 2,796 (gross).

Figure 54 · Non-Hydro Renewables and Nuclear Electricity Production in the World



Sources: BP Statistical Review and IAEA-PRIS, 2020

STATUS AND TRENDS IN CHINA, THE EUROPEAN UNION, INDIA, AND THE UNITED STATES

China

China is still the most important country in terms of renewable energy manufacturing and deployment. However, the latest Renewable Energy Country Attractiveness index, published by Ernst & Young, published in May 2020, drops China from the top spot, to second, behind the U.S.[1145] The reason given is that the Chinese Government has lowered market subsidies and the reduction in demand following the COVID-19 pandemic, that has affected demand for domestic use and for the manufacturing of goods for export.

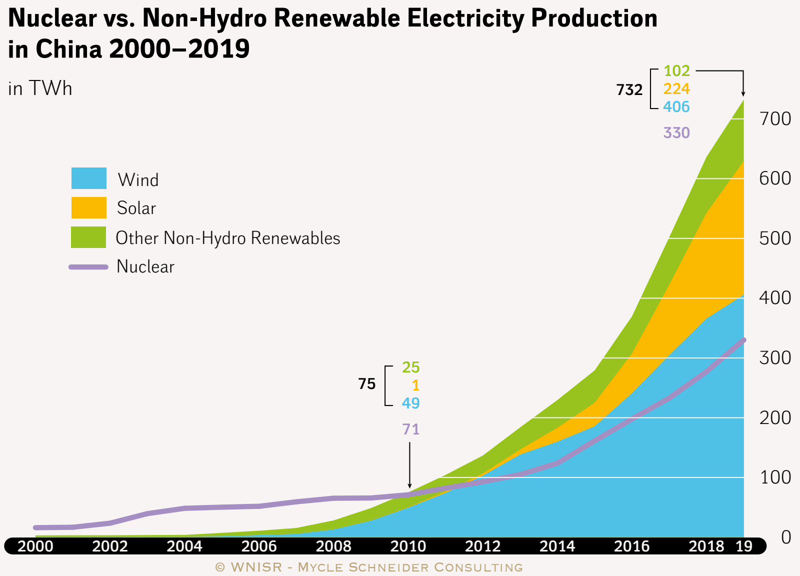
In the case of China, there are usually a range of numbers for the capacity and production volumes of energy, especially for renewable sources. According to the Government's National Energy Administration (NEA), by the end of 2019, the total installed capacity of renewable energy was 794 GW, up 9 percent on the previous year. This included 356 GW of hydro, 210 GW of wind, 204 GW of solar and 22.5 GW of biomass, which between them account for 39.5 percent of the installed capacity. In 2019, renewable-energy-based power generation reached 2,040 TWh, an increase of about 176.1 TWh year-on-year. As a result, renewable-energy power generation accounted for 27.9 percent of power generation, up 1.2 percentage points year-on-year.[1146]

1145 - EY, "Renewable Energy Country Attractiveness Index", May 2020, see https://www.ey.com/en_gl/recai, accessed 4 June 2020.

1146 - NEA, "NEA press conference on the 2019 status of renewable power generation", China Energy Portal, 6 March 2020 (in Chinese), see https://chinaenergyportal.org/nea-press-conference-on-the-2019-status-of-renewable-power-generation/, accessed 4 June 2020.

Compared to 2000, nuclear power generation increased 20-fold by 2019, while new renewables output—biomass, wind and solar, not including hydro—was virtually non-existent in 2000 (see Figure 55). In 2010, new renewables overtook nuclear output for the first time with 75 TWh vs. 71 TWh for nuclear. And although nuclear output grew by an impressive 4.6 times between 2010 and 2019, new renewables increased production more than twice as fast, 9.8 times, over the same period (see Figure 55).

Figure 55 · Nuclear vs Non-Hydro Renewables in China 2000–2019



Sources: IAEA-PRIS, BP Statistical Review, 2020

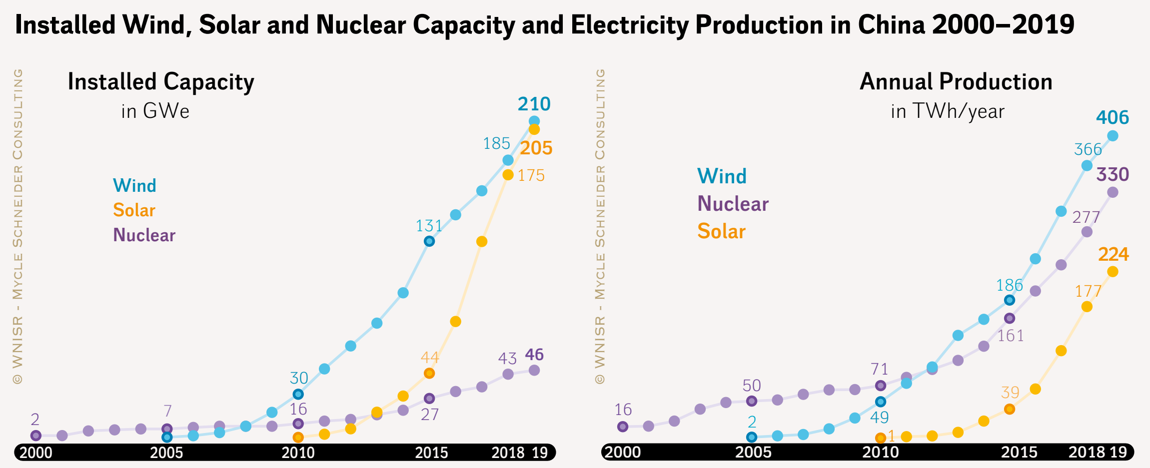
Despite the impressive total numbers, the annual capacity additions for solar PV in 2019 were significantly lower at just over 30 GW compared with 44 GW in 2018—a fall of 32 percent.[1147] In 2019, 17.9 GW of new solar was centralized and 12.2 GW were decentralized. While the rapidly increasing share of decentralized solar is a remarkable development, the total added capacity represents a further decline from the record deployment in 2017 of 53 GW (see Figure 56).

According to the NEA, PV power generation reached 224.3 TWh, which exceeded 200 TWh for the first time, a year-on-year increase of 26.3 percent. In July 2019, the country released results for its first national auction for solar PV projects and the NEA approved 22.78 GW of solar capacity with the lowest bid at CNY279.5/MWh (US$41/MWh), which is falling, but still significantly higher than in other countries, such as in the Middle East and US.[1148]

1147 - Globaldata Energy, "Solar PV capacity additions in China fell by 32% in 2019", *Power Technology*, 23 January 2020, see https://www.power-technology.com/comment/solar-pv-capacity-additions-china-2019/, accessed 4 June 2020.

1148 - Globaldata Energy, "Solar PV Capacity Additions in China Fell by 32% in 2019", see https://www.power-technology.com/comment/solar-pv-capacity-additions-china-2019/, accessed 6 July 2020.

Figure 56 · Installed Wind, Solar and Nuclear Capacity and Electricity Production in China 2000–2019



Sources: IRENA, BP Statistical Review, IAEA-PRIS, WNISR, 2020

Wind power in 2019 increased its annual deployment with an additional 26.2 GW of new capacity—44 percent of the global total[1149]—compared to a 21.2 GW increase in 2018[1150], according the Global Wind Energy Council. In 2019, about 2.3 GW of the new deployment was offshore—39 percent of the global total, the rest was onshore. China now has 37 percent of the world's wind power fleet. According to the NEA, the total electricity production was just under 406 TWh, exceeding 400 TWh for the first time, an increase of 10.9 percent year-on-year. Importantly, the level of wind curtailment, when the power generated cannot be used, fell to 4 percent, which is the continuation of an important trend within the sector. China is aiming to become a subsidy-free market from 2021 by eliminating feed-in-tariffs for wind and solar PV.[1151]

The 13th Five-Year Plan (2016–2020) proposed new targets for energy efficiency and the reduction of carbon intensity as well as diversification away from fossil fuels, whereby non-fossil fuels are to provide 15 percent of primary energy consumption by 2020, up from 7.4 percent in 2005.[1152] However, in 2016, a total of 34.5 GW of solar PV were installed, almost double the forecasted 15 to 20 GW per year.[1153] In November 2016, NEA announced an update of the 13th Five-Year Plan for the power sector (2016–2020). The target for wind power (210 GW) is higher than the previous announcements (200 GW), while the target for solar (110 GW) is considerably lower (up to 150 GW previously). Given the *real* deployment levels of solar and wind at the end of 2019, both over 200 GW, both targets have already been met.

1149 - GWEC, "GWEC: Over 60GW of wind energy capacity installed in 2019, the second-biggest year in history", Global Wind Energy Council, 25 March 2020, see https://gwec.net/gwec-over-60gw-of-wind-energy-capacity-installed-in-2019-the-second-biggest-year-in-history/, accessed 4 June 2020.

1150 - GWEC, "Global Wind Energy Report 2018", Global Wind Energy Council, April 2018, see https://gwec.net/wp-content/uploads/2019/04/GWEC-Global-Wind-Report-2018.pdf, accessed 23 June 2019.

1151 - Globaldata Energy, "Solar PV Capacity Additions in China Fell by 32% in 2019".

1152 - *China Dialogue*, "Climate, energy and China's 13th Five-Year Plan in graphics", 18 March 2016, see https://www.chinadialogue.net/article/show/single/en/8734-Climate-energy-and-China-s-13th-Five-Year-Plan-in-graphics, accessed 4 June 2020.

1153 - Richard Martin, "China Is on an Epic Solar Power Binge", *MIT Technology Review*, 22 March 2016, see https://www.technologyreview.com/2016/03/22/161462/china-is-on-an-epic-solar-power-binge/, accessed 4 June 2020.

The 13th Five-Year Plan was also proposing to increase nuclear capacities to a total of 58 GW by 2020 with an additional 30 GW under construction. However, only 44.5 GW are operating as of 1 July 2020, and 13.8 GW are under construction (see Overview of Current New-build). Therefore, it will be impossible to meet this target.

In mid-2020 the Chinese Government is preparing the 14th Five-Year Plan, with the final plan expected to be approved by China's top legislature in early 2021. Internationally, as part of the Paris Agreement, China has pledged to peak carbon emissions by 2030 at the latest but has been reluctant to promise an absolute cap on emissions. The 14th Five-Year Plan will also be affected by the stimulus package which is focusing on increasing electrification and the use of electric vehicles.

European Union

In the **European Union** (**EU**)[1154], renewables, including hydro, continue to grow and supplied a record 35 percent of the power in 2019, up by 1.8 percent over the previous year. During 2019, the combined outputs from solar and wind at 18 percent were greater than that provided by coal. The other renewables, hydro and biomass provided 10.8 percent and 6.2 percent respectively, while nuclear power provided 25.5 percent.[1155]

Figure 57 shows how over the past decade new renewables, particular solar and wind, having increased output by a factor of 2.5, while nuclear output dropped by more than 9 percent over the same period. In 2020, for the first time, the production of new renewables will almost certainly exceed that from nuclear plants.

As illustrated in Figure 58, in 2019, wind generation increased by 14 percent (+54 TWh) with 73 percent of the growth occurring in just five countries: France, Germany, Spain, Sweden and the U.K. Solar generation rose by 7 percent (+9.5 TWh) with the Netherlands (+3 TWh) and Spain (+2 TWh) accounting for 54 percent of the EU-wide increase in solar generation. Nuclear generation decreased slightly by 1 percent (–6 TWh), in particular due to a 3 percent decrease in France and a 14 percent drop in the U.K.

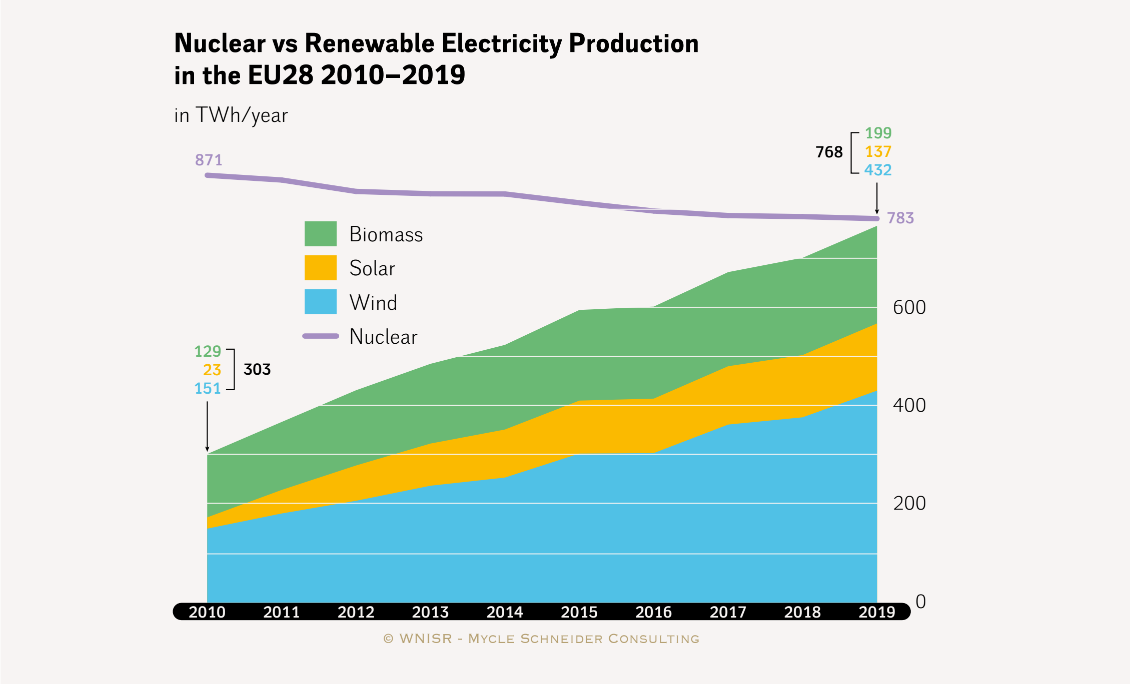
Overall fossil fuel generation fell by 6 percent, with natural gas increasing by 12 percent, hard coal decreasing by 32 percent—caused by renewables growth and rising CO_2 prices (leading to increased gas generation)—and a fall in lignite-based production of 16 percent. Electricity consumption decreased by 1.7 percent in 2019 (–56 TWh), bringing demand back to 2015 levels. Because of all of these changes CO2 emissions from the power sectors fell by 12 percent.[1156]

1154 - As the U.K. left the EU only on 31 January 2020, we are providing the statistics for 2019 for the EU28 including the U.K.

1155 - Agora Energiewende et al., "The European Power Sector in 2019: Up-to-Date Analysis on the Electricity Transition", February 2020, see https://www.agora-energiewende.de/en/publications/the-european-power-sector-in-2019/, accessed 20 June 2020.

1156 - Ibidem.

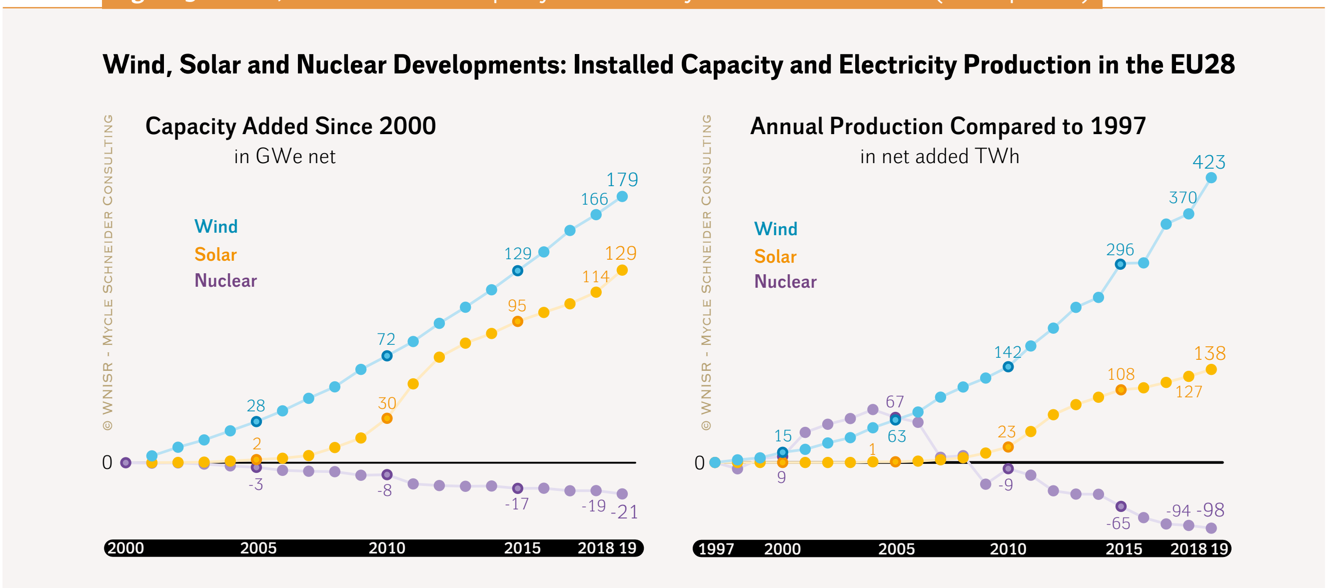
Figure 57 · Renewable Energy and Nuclear Power Generation in the EU28 2010–2019



Sources: IAEA-PRIS, Agora Energiewende/Sandbag[1157]

Since 2000, wind added 178.5 GW of installed capacity, solar 129.6 GW, while nuclear declined by 21 GW. Since the signature of the Kyoto Protocol in 1997, wind and solar increased annual production by 423 TWh and 138 TWh respectively, while nuclear generated 98 TWh less power than two decades earlier (see Figure 58).

Figure 58 · Wind, Solar and Nuclear Capacity and Electricity Production in the EU28 (Developments)

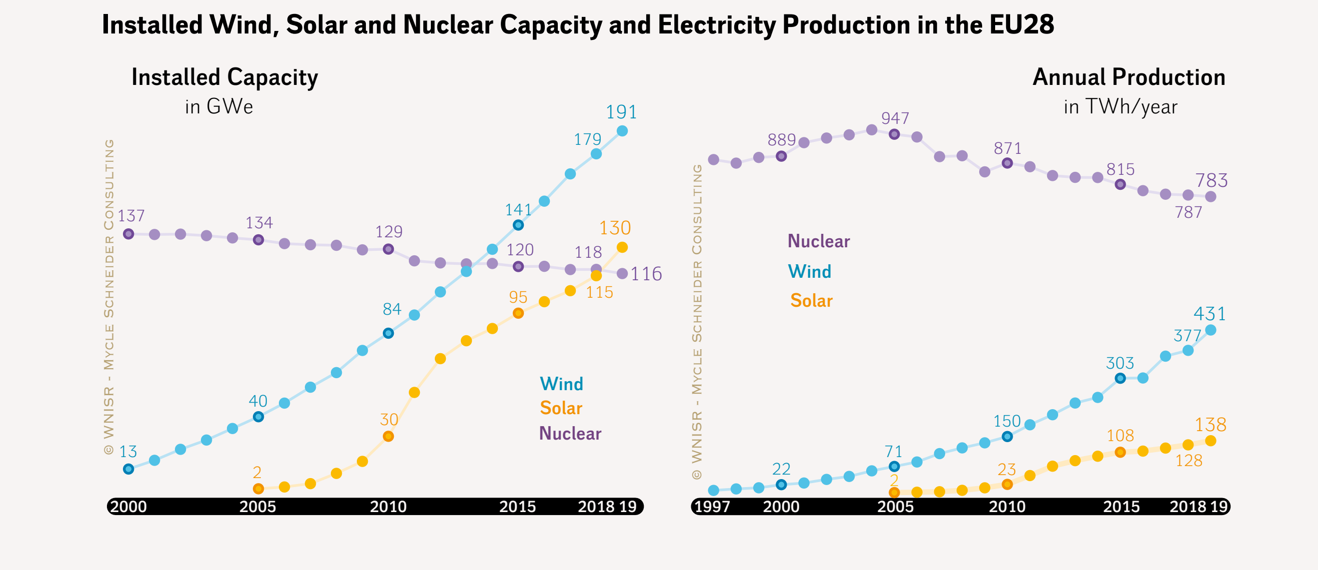


Sources: IRENA, BP, IAEA-PRIS, WNISR, 2020

1157 - Agora Energiewende et al., "The European Power Sector in 2019: Up-to-Date Analysis on the Electricity Transition", 2020, op. cit.

In 2019, solar installed capacity for the first time exceeded the nuclear one in the EU28 with 130 GW vs. 116 GW. Wind had outpaced nuclear already in the 2014 and has since enlarged the gap with a total of 191 GW installed as of the end of 2019. On the electricity generation side, nuclear is still generating more than either wind or solar, but its slow decline continues. (See Figure 59)

Figure 59 · Wind, Solar and Nuclear Capacity and Electricity Production in the EU28 (Absolute Numbers)



Sources: BP Statistical Review, IAEA-PRIS, IRENA, WNISR, 2020

The growth in renewable electricity production is set to continue beyond the current 2020 targets, as in preparation of the U.N. climate meeting in Paris in December 2015, the EU initially agreed a binding target of at least 27 percent renewables in the primary energy mix by 2030, which is likely to have meant 40–50 percent of power coming from renewables. However, in June 2018, it was agreed to increase ambition, with a new target of 32 percent of renewables in primary energy by 2030, with an opportunity to further increase this in 2023.[1158] By 2050, the EU aims for a completely low-carbon electricity system. This will require speeding up the current rate of renewable electricity deployment. There is no EU-wide nuclear deployment target.

During 2019, the costs of new renewable installations continued to fall in most countries. In France, 12 solar projects totaling 94.2 MW of capacity were selected to be built at the Fessenheim nuclear power station in France's Haut-Rhin department, which has been closed in the first half of 2020. The allocation—which attracted bids averaging €55.8–98.5/MWh (US$62–110/MWh)—was the result of the second round of the Fessenheim scheme, which ultimately aims to install 300 MW of solar in the vicinity of the nuclear site that is to be decommissioned.[1159] In Germany, the latest onshore wind auction prices are averaging €61.4/

1158 - European Commission, "Europe leads the global clean energy transition: Commission welcomes ambitious agreement on further renewable energy development in the EU", Press Release, 14 June 2018, see https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_18_4155, accessed 14 June 2020.

1159 - Sophie Vorrath, "France solar auction success delivered at nuclear's expense", *Renew Economy*, 3 April 2020 , see https://reneweconomy.com.au/france-solar-auction-success-delivered-at-nuclears-expense-59426/, accessed 6 April 2020.

MWh (US$69/MWh) and for solar €52.7/MWh (US$60/MWh).[1160] In the U.K., the Contracts for Difference (CfD) Allocation Round 3 for offshore wind, held in 2019, will be delivered at a strike price as low as £39.65/MWh (US$50/MWh).[1161]

The European Commission introduced a Green New Deal in order to meet medium- and long-term emissions-reduction objectives in 2019. This would enable the EU to move towards a net zero economy while maintaining economic growth. Following the global pandemic, the EU revised this and in May 2020 published a green recovery plan, which assumes that investment needs amount to at least €1.5 trillion (~US$1.1 trillion) in 2020–2021. "Investment in key sectors and technologies, from 5G to artificial intelligence and from clean hydrogen to offshore renewable energy, holds the key to Europe's future".[1162]

The European Commission has developed a taxonomy framework to facilitate sustainable investment. The text agreed by the European institutions (the European Parliament and Council), notes that renewable energy is an economic activity that contributes to climate change mitigation, but no mention is made of nuclear power. The regulation asked a Technical Expert Group (TEG) to:

> develop recommendations for technical screening criteria for economic activities that can make a substantial contribution to climate change mitigation or adaptation, while avoiding significant harm to the four other environmental objective.[1163]

The Group concluded on nuclear power:

> It was not possible for TEG, nor its members, to conclude that the nuclear energy value chain does not cause significant harm to other environmental objectives on the time scales in question. The TEG has therefore not recommended the inclusion of nuclear energy in the Taxonomy at this stage.[1164]

This is a significant development, as the EU stimulus package is designed to use additional EU and Member State funds to rebuild parts of the economy while meeting decarbonization objectives. Not including nuclear power within the funding framework will further increase the gap between renewables and nuclear power with greater deployment leading to cheaper and cheaper solar and wind, and in relation to policy support.

1160 - *reNEWS.BIZ*, "Latest German onshore auction lacks allure", 24 June 2020, see https://renews.biz/61205/latest-german-onshore-auction-lacks-allure/, accessed 5 July 2020.

1161 - *reNEWS.BIZ*, "UK offshore wind 'cheaper than new nuclear'", 25 June 2020, see https://renews.biz/61228/uk-offshore-wind-cheaper-than-new-nuclear/, accessed 26 June 2020.

1162 - European Commission, "The EU budget powering the Recovery Plan for Europe", 27 May 2020, see https://ec.europa.eu/info/files/eu-budget-powering-recovery-plan-europe_en, accessed 14 June 2020.

1163 - Council of the European Union, "Proposal for a Regulation of the European Parliament and the Council on the establishment of a framework to facilitate sustainable investment - Approval of the final compromise text", Interinstitutional File 2018/0178 (COD), 17 December 2020, see https://data.consilium.europa.eu/doc/document/ST-14970-2019-ADD-1/en/pdf, accessed 14 June 2020.

1164 - European Commission, "Technical annex to the TEG final report on the EU taxonomy", 9 March 2020, see https://ec.europa.eu/info/files/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en, accessed 14 June 2020.

India

According to IRENA, since 2010, the capacity of solar has increased from 65 MW to 35 GW at the end of 2019, while wind increased from 13 GW to 37.5 GW.[1165] Figure 60 shows that since the turn of the century, wind power output has grown rapidly, from 1.5 TWh to 63.3 TWh in 2019[1166] and has overtaken nuclear's contribution to electricity generation since 2016, which now stands at 45.2 TWh. Solar is also growing rapidly, from 7 MWh in 2000 to 46.3 TWh in 2019, having overtaken nuclear power for the first time. The differences 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.

India has put in place ambitious targets for the deployment of renewables 175 GW by 2022 including 100 GW solar and 60 GW wind. Between 2014 and 2018, the annual growth of the new-renewable energy sector increased tenfold from 2.6 GW to 28 GW—a cumulative aggregated growth rate of around 18 percent.[1167] However, the growth rate has now slowed. At the start of financial year 2019–2020, the Ministry of New and Renewable Energy (MNRE) agree to add 11.8 GW of renewable energy capacity. This target was the lowest in four years, yet deployment levels failed to achieve it. During the period of April 2019 to March 2020, the country managed to add 8.7 GW of renewable energy capacity, a shortfall of 26 percent.[1168]

The failure to meet targets is despite world beating falling costs. IRENA reported that India had the lowest installation costs for solar PV power plants in both 2018 and 2019. The global weighted-average total installed cost of projects commissioned in 2019 fell, to US$995/kW with India having the lowest costs of US$618/kW. While the LCOE between 2010 and 2019 in India declined by 85 percent to reach US$45/MWh in 2019—34 percent lower than the global weighted average, according to IRENA figures.[1169]

In 2019, the global weighted-average LCOE of onshore wind stood at US$53/MWh, but in India it had fallen to US$49/MWh and is now lower than the cheapest fossil fuel-fired option.[1170] It is notable that with the auctions for both solar and wind power there is maximum price disclosure, which contrasts with the nuclear sector, where there is little information. However, one academic analysis suggests that costs for light water reactors are around US$140/MWh depending on the waste management strategy.[1171]

1165 - BP, "Statistical Review of World Energy 2020: a pivotal moment", Press Release, 17 June 2020, see https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-statistical-review-of-world-energy-2020-published.html, accessed 26 June 2020.

1166 - BP, "Statistical Review of World Energy", 2020, see https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/xlsx/energy-economics/statistical-review/bp-stats-review-2020-all-data.xlsx, accessed 17 June 2020.

1167 - *Economic Times of India*, "India may find it difficult to meet 175 GW renewable energy capacity target by 2022, says think tank", 12 February 2020, see https://economictimes.indiatimes.com/small-biz/productline/power-generation/india-may-find-it-difficult-to-meet-175-gw-renewable-energy-capacity-target-by-2022-says-think-tank/articleshow/74094698.cms?from=mdr, accessed 14 June 2020.

1168 - *CleanTechnica*, "India Misses Renewable Energy Targets In 4th Consecutive Year", 23 May 2020, see https://cleantechnica.com/2020/05/23/india-misses-renewable-energy-targets-in-fourth-consecutive-year/, accessed 14 June 2020.

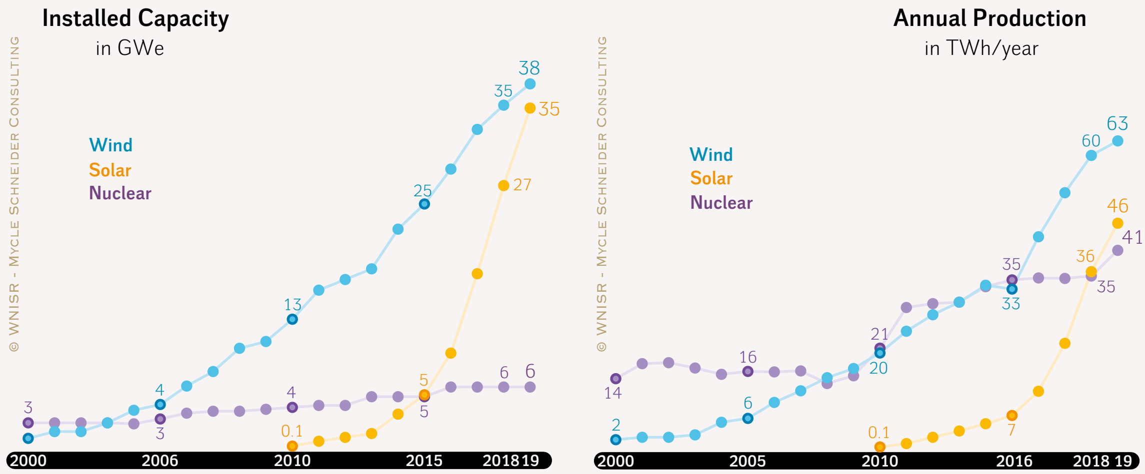
1169 - IRENA, "Renewable Power Generation Costs in 2019", June 2020, see https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019, accessed 13 June 2020.

1170 - Ibidem.

1171 - Anoop Singh et al., "Levelised Cost of Electricity for Nuclear Power Using Light Water Reactor Technology in India", *Economic and Political Weekly*, 10 March 2018.

Figure 60 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in India

Installed Wind, Solar and Nuclear Capacity and Electricity Production in India 2000–2019



Sources: BP Statistical Review, IRENA, IAEA-PRIS, WNISR, 2020

United States

Despite pledges by the incoming Trump administration to support the coal and nuclear sectors, neither have thrived, on the contrary: in 2019, coal consumption decreased for the sixth consecutive year to 11.3 quadrillion Btu, the lowest level since 1964. Electricity generation from coal also declined significantly over the past decade and, in 2019, fell to its lowest level in 42 years. In April 2019, for the first time since before 1885, the renewable energy sector (hydro, biomass, wind, solar and geothermal) generated more electricity than coal-fired plants across the U.S.[1172] In 2019, 23 GW of new production capacity was installed, of which 9.1 GW was wind, 8.3 GW natural gas and 5.3 GW solar PV.[1173] For the first time, installed wind power exceeded installed nuclear capacity with 104 GW vs. 98 GW (see Figure 61).

No new nuclear power capacity came on-line for the past four years and one reactor (Three-Mile-Island-1) was closed in September 2019, and yet the industry succeeded in generating a new record volume of electricity with 809 TWh supplying just under 20 percent of the electricity. Across the U.S., there are 30 states with operating nuclear power plants, and 12 of these generated more than 30 percent of their power from their reactors.

As solar and wind continue to be deployed at scale, their installation costs keep falling and therefore, so does the cost of electricity they produce. Consequently, the combined fuel, maintenance, and other going-forward costs of coal-fired power from many existing plants is now more expensive than the all-in costs of new wind or solar projects. Energy Innovation partnered with Vibrant Clean Energy (VCE) research finds that in 2018, 211 GW of existing (end of 2017) U.S. coal capacity, or 74 percent of the national fleet, was at risk from local wind

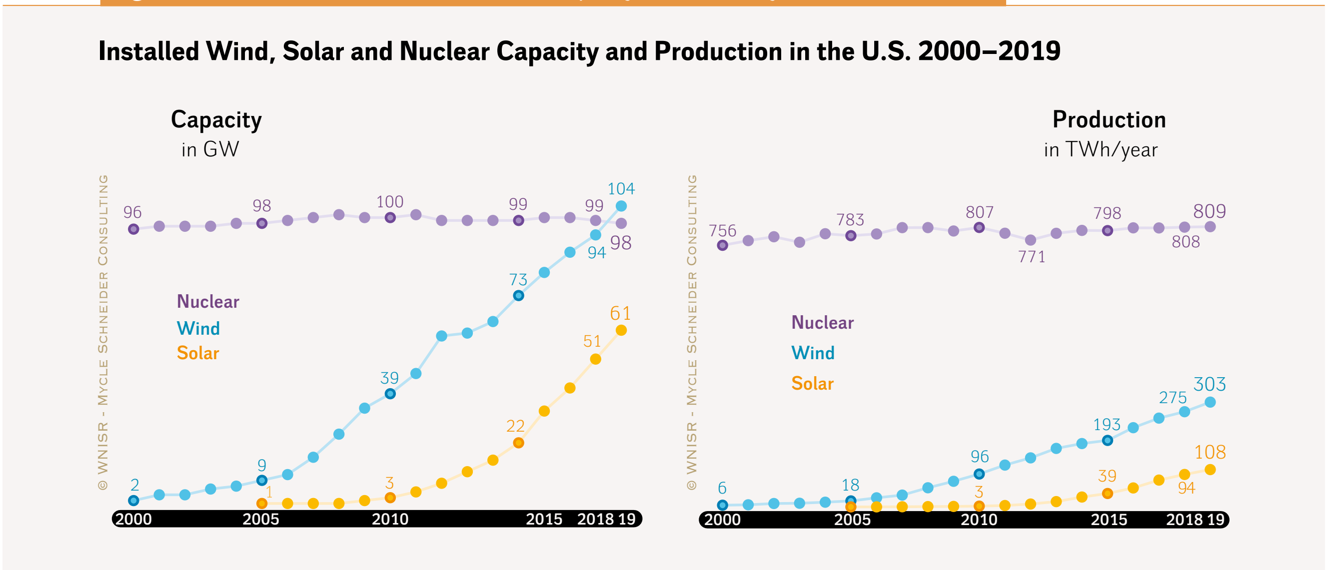
1172 - Mickey Francis, "U.S. renewable energy consumption surpasses coal for the first time in over 130 years", *Today in Energy*, U.S. EIA, 28 May 2020, see https://www.eia.gov/todayinenergy/detail.php?id=43895, accessed 4 June 2020.

1173 - Manussawee Sukunta, "Wind and natural gas-fired generators led U.S. power sector capacity additions in 2019", U.S. EIA, April 2020, see https://www.eia.gov/todayinenergy/detail.php?id=43415, accessed 4 June 2020.

or solar that could provide the same amount of electricity more cheaply. By 2025, at-risk coal increases to 246 GW, nearly the entire U.S. fleet.[1174] The Institute for Energy Economics and Financial Analysis (IEEFA) projected in November 2019 that renewables would fully outpace coal-fired generation on an annual basis in 2021. By March 2020, they had assumed that "the transition in fact is gaining speed as utilities phase out coal-fired generation and turn to gas and renewables". They further assume that renewables contribution, excluding that from distributed solar, will exceed that of nuclear power by 2024.[1175]

Despite support from the White House, nuclear power and coal have not thrived under the Trump Presidency, which is primarily due to support on the State level for renewables and basic economics. Across the U.S., as was shown by the Lazard assessment (see Figure 50), costs of renewables continue to fall and are significantly cheaper than nuclear new build.

Figure 61 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in the U.S



Sources: BP Statistical Review, IRENA, IAEA-PRIS, WNISR 2020

CONCLUSION ON NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

In June 2020, the IEA put forward a three-year Sustainable Recovery Plan, "focused on cost-effective measures that could be implemented during the specific timeframe of 2021 to 2023".[1176] The plan has three main goals: boosting economic growth, creating jobs and building

1174 - Eric Gimon, Christopher T M Clack and Sarah Mckee, "The coal cost crossover: economic viability of existing coal compared to new local wind and solar resources", *Energy Innovation and Vibrant Clean Energy*, March 2019.

1175 - Dennis Warmsted, Seith Feaster and Karl Cates, "U.S. Coal Outlook 2020: Market Trends Pushing Industry Ever Closer to a Reckoning", IEEFA, Institute for Energy Economics and Financial Analysis, March 2020, see https://ieefa.org/wp-content/uploads/2020/03/US-Coal-Outlook-2020_March-2020.pdf, accessed 5 July 2020.

1176 - IEA, Sustainable Recovery - World Energy Outlook Special Report.

more resilient and cleaner energy systems. The proposal for the power sector suggested a prioritization of investment in renewable energy and a strengthening of the grid, such that

> a range of measures could be put in place to support the expansion and modernization of electricity grids; accelerate new wind and solar installations and repower existing ones.

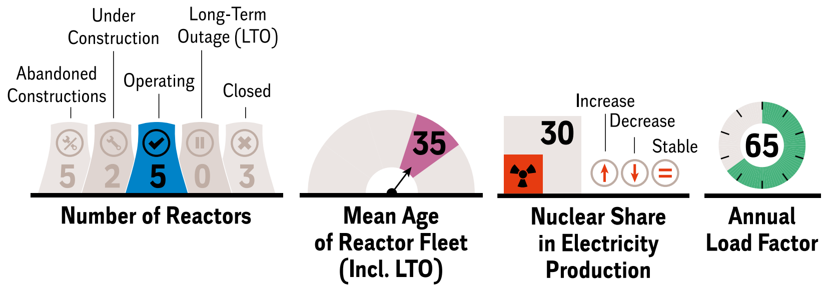
For all other energy sources, including nuclear power, the IEA suggests that they should be maintained or managed. The message is clear: for economic, employment and sustainability reasons the clear priority is renewable energy.

The IEA's conclusions—echoed in this chapter—if enacted, will accelerate a trend that has been seen over the past decade, at least, that nuclear power appears increasingly as an outdated, incompatible and expensive technology that cannot compete in a decarbonized energy sector with the range of cheaper renewable energy sources.

TABLE OF ANNEX

ANNEX 1 – OVERVIEW BY REGION AND COUNTRY

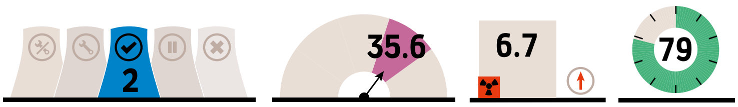
These "quick view" indicators will be used in the country sections throughout the report.



Unless otherwise noted, data on the numbers of reactors operating and under construction and their capacity (as of mid-2020) and nuclear's share in electricity generation in 2019 are from the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS) online database.[1177] Historical maximum figures indicate the year that the nuclear share in the power generation of a given country was the highest since 1986, the year of the Chernobyl disaster. Unless otherwise noted, the load factor figures are from *Nuclear Engineering International* (*NEI*).[1178]

AFRICA

South Africa



Africa's only commercial nuclear power plant houses two 900 MW reactors, located at Koeberg, near Cape Town in South Africa. Both reactors started operating in the mid-1980s. In 2019, they generated 13.6 TWh representing 6.7 percent of the country's power, an increase of 2 percentage points over the previous year, but down from the historical maximum of 7.4 percent in 1989.

The reactors had been given permission to operate for 40 years and are now planning a series of replacement and upgrading work to extend their operational lifetimes.[1179] The decision to replace all six steam generators of the two units was taken in 2010. AREVA was awarded the contract in 2014[1180] and a lengthy legal battle with competitor Westinghouse followed. In 2018, the Parliament began investigations into the actions of several Eskom officials relating to a number of issues, 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

1177 - IAEA-PRIS, "Nuclear Share of Electricity Generation in 2019", see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

1178 - NEI, "Load factors to end December 2019", June 2020.

1179 - Kevin Brandt, "Koeberg nuclear plant components can run beyond 2045, say experts", *EWN*, 5 November 2019, see https://ewn.co.za/2019/11/05/koeberg-nuclear-plant-components-can-run-beyond-2045-say-experts, accessed 5 November 2019.

1180 - *NEI*, "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 5 June 2020.

some contracts, including those relating to the steam generator replacement "may constitute criminal conduct".[1181]

The plant has been operating at low temperatures to reduce the pace of corrosion in the steam generator tubes. The replacement of the steam generators is scheduled to be carried out in 2021.[1182]

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 give 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.[1183]

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; halting a December 2015 decision to proceed with the procurement of 9.6 GW of new nuclear capacity, and annulling 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.[1184] In May 2017, the Government announced that it would not appeal the court. The 2018 Goldman environmental prize was awarded to grassroots activists Makoma Lekalakala and Liz McDaid for the successful legal challenge in this case.[1185]

In January 2018, future President Cyril Ramaphosa said in Davos that "we have no money to go for major nuclear plant building."1186 Even the chief financial officer of Eskom stated: "I can't go and commit to additional expenditure around a nuclear program."[1187] In August 2018, the Government published its draft IRP 2018[1188], in which new nuclear is absent in the period up to 2030.[1189]

1181 - Renee Bonorchis and Ana Monteiro, "Three former Eskom chairmen to be criminally probed", *Bloomberg*, as published by *BizNews.com*, 28 November 2018, see https://www.biznews.com/briefs/2018/11/28/eskom-chairmen-criminal-probe, accessed 5 June 2020.

1182 - According to an Eskom spokesperson, personal communication, Anton Eberhard, email dated 13 July 2020.

1183 - *NEI*, "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 5 June 2020.

1184 - Phil Chaffee, "Legal, High Court Upends South African Newbuild Plans", *NIW*, 28 April 2017.

1185 - 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 5 June 2020.

1186 - Alexis Akwagyiram, "South Africa has no money for major nuclear expansion, Ramaphosa says", *Reuters*, 25 January 2018, see https://af.reuters.com/article/commoditiesNews/idAFL8N1PK6S9, accessed 5 June 2020.

1187 - *NIW*, "Weekly Roundup", 2 February 2018.

1188 - 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.

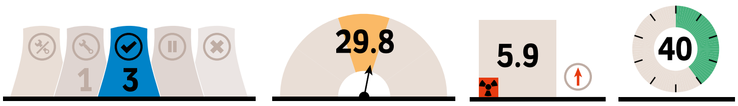
1189 - *NEI*, "South Africa cancels nuclear expansion plans", 30 August 2018, see https://www.neimagazine.com/news/newssouth-africa-cancels-nuclear-expansion-plans-6728356/, accessed 5 June 2020.

However, in October 2019, in the updated IRP document, nuclear power was described as a "no regret option". The document stated that due to expected decommissioning of 24 GW of coal capacity, it was proposed to implement nuclear "at an affordable pace and modular scale" and "at a pace and scale the country can afford".[1190]

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. It is not clear whether the RfI will be followed by a Request for Proposals, i.e. a formal, competitive tender, and it is unlikely that a further nuclear power plant will be started up in South Africa this decade.[1191]

THE AMERICAS

Argentina



Argentina has three nuclear reactors. In 2019, the operating units provided 7.9 TWh or 5.9 percent of the country's electricity (down from a maximum of 19.8 percent in 1990, but up on the previous year). The plants were supplied by foreign reactor builders: Atucha-1, which started operation in 1974, was supplied by Siemens, and the CANDU (CANadian Deuterium Uranium) type reactor at Embalse was supplied by Canadian Atomic Energy of Canada Limited (AECL) and started operating in 1983. In April 2018, the regulatory authority gave a lifetime extension license to enable Atucha-1 to continue operating until 2024, which would thus allow for a 50-year operating life.[1192]

The Embalse plant was shut down at the end of 2015 for major overhaul, including the replacement of hundreds of pressure tubes, to enable it to operate for up to 30 more years. Reportedly, contracts worth US$444 million were signed in August 2011 with the bulk of the work done during a 20-month shutdown starting in November 2013.[1193] According to the World Nuclear Association (WNA), the reactor was shut down in December 2015, completed in December 2018 and eventually returned to service in May 2019.[1194] It is now expected to operate for another 30 years.[1195]

Atucha-2 was ordered in 1979 and was listed as "under construction" in 1981. Construction was on and off for the following decades, but finally grid connection was announced on

1190 - Department of Mineral Resources and Energy, "Integrated Resource Plan (IRP2019)", Republic of South Africa, see http://www.energy.gov.za/IRP/2019/IRP-2019.pdf, accessed 5 June 2020.

1191 - Roger Murray and Phil Chaffee, "Government RFI Keeps New Nuclear Option Alive", *NIW*, 19 June 2020.

1192 - *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 1 June 2020.

1193 - *WNN*, "Embalse refurbishment contracts signed", 25 August 2011, see http://www.world-nuclear-news.org/C-Embalse_refurbishment_contracts_signed-2508114.html, accessed 1 June 2020.

1194 - WNA, "Nuclear Power in Argentina", Updated April 2020, see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx, accessed 1 June 2020.

1195 - *NEI*, "Argentina's Embalse resumes commercial operation", 5 June 2019, see https://www.neimagazine.com/news/newsargentinas-embalse-resumes-commercial-operation-7244154/, accessed 10 May 2020.

27 June 2014. However, it took until 19 February 2015 for the unit to reach full capacity[1196] and until 26 May 2016 to enter commercial operation.[1197]

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.[1198]

A framework agreement was also signed in 2015 between the two companies for the construction of a Hualong One reactor, China's new, and as yet unoperated, Generation-III design, without a site being specified.1199 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 2020.1200 However, the site for the Hualong reactor has not been agreed on, as the Governor of Rio Negro—the Government's preferred location—rejected the location of the reactor in his province, citing a lack of social acceptance for the project.1201 Despite this, the Government insisted in October 2017 that construction on both projects would begin in the 2nd half of 2018.1202 The total cost of the Hualong and Atucha-3 projects were expected to be US$12.5 billion, (other sources indicate US$15 billion)[1203] 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.[1204]

Then, in the run up to the G-20 summit in Buenos Aires at the end of 2018, there was more optimism that the project could be revised, due to a better financial offer from the Chinese and the conclusion of a wider bailout deal with the International Monetary Fund (IMF). During 2019, discussions were said to be still ongoing and centered around interest rates, although this was said to be just one of many issues to be resolved.[1205] According to a January 2019 note by the French Economy and Finance Ministry, the Hualong One project with a 750 MW reactor could be entirely financed by China and started up by 2027 or 2028.[1206] In June 2019, the Argentine Government expressed ongoing support for the project following official meetings

1196 - *WNN*, "Atucha 2 reaches 100% rated power", 19 February 2015, see http://www.world-nuclear-news.org/NN-Atucha-2-reaches-100-percent-rated-power-19021502.html, accessed 2 June 2020.

1197 - *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 2 June 2020.

1198 - *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 2 June 2020.

1199 - Phil Chaffee and Jason Fargo, "Moving closer to Atucha-3 and HPR1000 Newbuilds", *NIW*, 6 November 2015.

1200 - CNNC, "CNNC to build heavy water reactor and HPR 1000 units in Argentina", 19 May 2017, see http://en.cnnc.com.cn/2017-05/19/c_77725.htm, accessed 2 June 2020.

1201 - Phil Chaffee, "Argentina", *NIW*, 29 September 2017.

1202 - Sylvia Westall, "Argentina to start building two new nuclear reactors in 2018", *Reuters*, 31 October 2017, see https://www.reuters.com/article/argentina-nuclearpower/argentina-to-start-building-two-new-nuclear-reactors-in-2018-idUSL8N1N67EG, accessed 2 June 2020.

1203 - *WNN*, "Argentina and China sign contract for two reactors", 18 May 2017, see https://www.world-nuclear-news.org/NN-Argentina-and-China-sign-contract-for-two-reactors-1805175.html, accessed 2 June 2020.

1204 - Phil Chaffee, "The Fallout From Argentina's Newbuild Retreat", *NIW*, 25 May 2018.

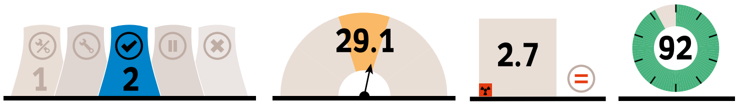
1205 - *NIW*, "Briefs–Argentina", 5 April 2019.

1206 - Direction générale du Trésor, "Le secteur nucléaire en Argentine", French Ministry for the Economy and Finance, 28 January 2019, see https://www.tresor.economie.gouv.fr/Articles/2019/01/28/le-secteur-nucleaire-en-argentine, accessed 16 May 2019.

with the Chinese, with Argentina's cabinet chief Marcos Pena saying "there is an intention to move forward."[1207] While 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.[1208]

After repeated delays, construction of a prototype 27-MWe PWR, the domestically designed CAREM25 (Central Argentina de Elementos Modulares—a pressurized-water SMR) began near the Atucha site in February 2014, with startup initially planned for 2018. The reactor was said to cost US$446 million[1209]. In 2019, it was rescheduled to begin operating in 2022,[1210] with the expected costs having risen to an estimated US$700 million or about US$26,000 per installed kWe.[1211] However, late in 2019, Techint Engineering & Construction, the main contractors 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; there is no indication about the impact this would have on project's timeline.[1212]

Brazil



Brazil operates two nuclear reactors that provided the country with 15.2 TWh or 2.7 percent of its electricity in 2019, just as in 2017, well below the maximum of 4.3 percent in 2001. Construction of a third reactor was suspended in late 2015.

The first contract for the construction of a nuclear power plant, Angra-1, was awarded to Westinghouse in 1970. The reactor eventually went critical in 1981. Angra-2 was connected to the grid in July 2000, 24 years after construction started. Preparatory work for the construction of Angra-3 started in 1984, although it is unclear how much progress was made. Then, in May 2010, Brazil's Nuclear Energy Commission issued a construction license and the IAEA noted that a "new" construction started on 1 June 2010. In early 2011, the Brazilian national development bank (BNDES) approved a BRL6.1-billion (US$3.6-billion)-loan for work on the project.[1213] Reportedly, in November 2013, utility Eletronuclear, subsidiary of state-owned Eletrobras, signed a €1.25 billion (US$ $_{2013}$1.67 billion) contract with French builder AREVA for

1207 - Cassandra Garrison and Hugh Bronstein, "Argentine official, in China, talks nuclear deal and soymeal", *Reuters*, as published by *TheGuardian.pe.ca*, 25 June 2019, see https://www.theguardian.pe.ca/business/argentine-official-in-china-talks-nuclear-deal-and-soymeal-326387/, accessed 2 June 2020.

1208 - *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 3 May 2020.

1209 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 2 June 2020.

1210 - Matías Alonso, "CAREM: Reactor en alta tensión", *Agencia TSS*, 21 February 2019 (in Spanish), see http://www.unsam.edu.ar/tss/carem-reactor-en-alta-tension/, accessed 2 June 2020.

1211 - Jim Green, "Small and Medium Nuclear Reactors (SMRs) – cost estimates, and what they cost to build", *Nuclear Monitor*, as published on *Nuclear-News*, 7 March 2019, see https://nuclear-news.net/2019/03/25/small-and-medium-nuclear-reactors-smrs-cost-estimates-and-what-they-cost-to-build/#more-147114, accessed 12 May 2019.

1212 - *Nucnet*, "Argentina Plans To Revive CAREM-25 SMR", *Energy Central*, 26 April 2020, see https://energycentral.com/c/ec/argentina-plans-revive-carem-25-smr, accessed 3 May 2020.

1213 - However, it is surprising to note that AREVA's 400-page Reference Document 2012 does not even contain the word "Angra"; see AREVA, "2012—Reference Document", 2013, see http://www.sa.areva.com/mediatheque/liblocal/docs/groupe/Document-reference/2012/DDR_AREVA_2012_EN.pdf, accessed 2 June 2020.

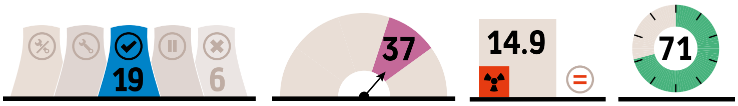
the completion of the plant.[1214] Commissioning was previously planned for July 2016 but was delayed to May 2018 in 2015,[1215] and by February 2016, the following deadline of mid-2019 was "already being reevaluated".[1216]

In June 2019, the industry invited 10 foreign firms to express interest in a partnership for the completion of the project. Leonam Guimaraes, president of Eletronuclear (the Eletrobas subsidiary), announced in October 2019 that Angra-3 would be completed with either CNNC, Rosatom or EDF and that the costs would be around US$3.7 billion, despite apparently being 70 percent complete, with 80 percent of the nuclear equipment already purchased.[1217] As of May 2020, Angra-3 grid connection was planned for November 2026.[1218]

In an effort to restart construction, the Government has agreed a long-term power purchasing-agreement for Angra-3 of BRL480/MWh (US$115/MWh).[1219] In June 2020, the Government approved plans for the completion of the project, "with or without a partner joining Eletronuclear". This is despite the President of Eletronuclear suggesting that an additional BRL14.5 billion (US$2.65 billion) of investment would be needed to complete the unit.[1220] As with other construction projects, preparatory work at the Angra plant has slowed as a result of the COVID-19 pandemic, which is likely to further impact upon the completion schedule.[1221]

Despite the lack of construction the project has created political scandals and even the former Brazilian President Michel Temer has become involved and arrested, along with others, in March 2019, for allegedly diverting BRL1.8 billion (US$475 million) from Eletronuclear's Angra-3 new-build project.[1222] (See also earlier WNISR editions).

Canada



Canada has 19 CANDU reactors that produced 94.9 TWh in 2019, or 14.9 percent of Canada's total electricity. Both were almost identical to the 2018 figures. 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 61 percent of the electricity generated in 2019.[1223]

1214 - *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 2 June 2020.

1215 - *NIW*, "Briefs – Brazil", 9 January 2015.

1216 - NIW, "Brazil: Politics, Corruption and Finances Grind Angra-3 to a Halt", 19 August 2016.

1217 - *NEI*, "Brazil seeks partners to complete Angra 3", 29 October 2019, see https://www.neimagazine.com/news/newsbrazil-seeks-partners-to-complete-angra-3-7478476/, accessed 6 May 2020.

1218 - *NW*, "Brazil postpones long-term energy plan and proposal for 10 GW of new nuclear capacity", 21 May 2020.

1219 - Phil Chaffee, "Angra-3 Financing Plan Approved", *NIW*, 12 June 2020.

1220 - Marcela Ayres and Anthony Boadle, "UPDATE 1-Brazil government approves plan to complete third nuclear plant", *Reuters*, 10 June 2020, see https://af.reuters.com/article/energyOilNews/idAFL1N2DN367, accessed 11 June 2020.

1221 - BNamericas, "COVID-19: What next for Brazil's Angra 3 nuclear plant?", 15 June 2020, see https://www.bnamericas.com/en/news/covid-19-what-next-for-brazils-angra-3-nuclear-plant, accessed 15 June 2020.

1222 - *NIW*, "Brazil: 'Radioactivity' Probe Nets Ex-President; Shoot-Out Near Angra", 22 March 2019.

1223 - IESO, "Supply Overview", Independent Electricity System Operator, 2020, see http://ieso.ca/Power-Data/Supply-Overview/Transmission-Connected-Generation, accessed 23 March 2020.

Most of Canada's electricity comes from renewable sources. In 2019, renewables (including hydro) contributed close to 65 percent of the total electricity generated, slightly lower than the 2018 share.[1224] Renewable electricity is dominated by hydro power, which contributed over 58 percent of all of Canada's 666 TWh generated in 2019; of the remaining, wind contributed 5.1 percent, biomass 1.6 percent, and solar 0.6 percent. While hydro power's contribution is lower than the 2018 figure, the share of all the other renewables has increased slightly from the corresponding figures in 2018. According to IRENA, in the past decade, Canada's total renewable electricity capacity has grown from 80.8 GW (2010) to 101 GW (2019), hydropower from 75 GW (2010) to 81 GW (2019), wind from 4 GW (2010) to 13.4 GW (2019), and solar from 0.2 GW (2010) to 3.3 GW (2019).[1225]

The Canada Energy Regulator (or CER, previously the National Energy Board or NEB), now projects a declining trend for nuclear power. In the CER's 2019 "Energy Future" report, the latest available as of July 2020, the reference scenario involves the nuclear share of total electricity generation decreasing from 14.8 percent in 2018 to 11.2 percent in 2040. Its projection for renewables seems quite modest, since it foresees wind and solar energy supplying only just over 10 percent of all electricity.[1226] However, the decline of nuclear power could be more rapid than CER's projections, which presume that nearly all of the reactors operating today will be refurbished and kept operational. The only nuclear power plant that is not to be refurbished is the Pickering plant with six operating reactors; these are scheduled to be shut down in 2024.

Those refurbishments that are expected to occur are contingent on their costs remaining within expected amounts and ongoing expenditures being economically justified.[1227] Both of these assumptions are questionable. The Darlington-2 refurbishment project was scheduled to wrap up in the first quarter (Q1) of 2020 but was completed only on 4 June 2020[1228], with the reactor restarting and thus leaving the LTO status. The start of refurbishment at Darlington-3 has been delayed as well, in part due to the COVID-19 pandemic, and is now scheduled for Fall 2020 instead of Spring 2020.[1229] Historically, these delays have been accompanied by significant cost overruns.

With the ongoing decline in costs of solar and wind power, and of batteries and other electricity storage technologies, it becomes cheaper to meet electricity needs reliably using

1224 - BP, "Statistical Review of World Energy 2020", BP, June 2020,
see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 17 June 2020.

1225 - IRENA, "Renewable Capacity Statistics 2020", International Renewable Energy Agency, 2020,
see https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020, accessed 24 April 2020.

1226 - CER, "Canada's Energy Future 2019—Energy Supply and Demand Projections to 2040", Canada Energy Regulator, 2019,
see http://www.cer-rec.gc.ca/nrg/ntgrtd/ftr/index-eng.html, accessed 5 August 2020.

1227 - FAO, "An Assessment of the Financial Risks of the Nuclear Refurbishment Plan", Financial Accountability Office of Ontario, 21 November 2017.

1228 - OPG, "Darlington Unit 2 powers on", Ontario Power Generation, 4 June 2020, see https://www.opg.com/news/darlington-unit-2-powers-on/, accessed 12 July 2020;
and Jennifer O'Meara, "Darlington nuclear power plant refurbishment hits delay", *Toronto Star*, 19 August 2019,
see https://www.thestar.com/news/gta/2019/08/19/darlington-nuclear-power-plant-refurbishment-hits-delay.html, accessed 4 March 2020.

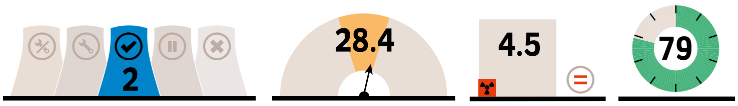
1229 - OPG, "OPG targets fall date for Unit 3 refurbishment in response to COVID-19", Ontario Power Generation, 2 April 2020,
see https://www.opg.com/news/opg-targets-fall-date-for-unit-3-refurbishment-due-to-covid-19/, accessed 12 July 2020.

these resources than nuclear power.[1230] Going through with nuclear reactor refurbishment will increase electricity bills for ratepayers.[1231]

At the same time, many Canadian provinces have elected leaders who have promised to either promote fossil fuels or curtail renewables. The Governments of two large Canadian provinces, Ontario and Alberta, have recently terminated procurement projects aimed at encouraging development of large renewable projects.[1232] These policy changes will likely impede the future of renewables in those provinces.

In contrast, several federal government agencies, and some provincial governments, continue to promote nuclear power, including the development of SMRs. This promotion is sought to be justified by referring to the challenges posed by climate change. During a keynote address to the Canadian Nuclear Association in February 2020, for example, Federal Natural Resources Minister, Seamus O'Regan stated, "this is nuclear's moment [...] to move to the frontlines in the battle against climate change and the plan to get Canada to net zero by 2050."[1233] In December 2019, the three Canadian Premiers of Saskatchewan, Ontario, and New Brunswick announced a Memorandum of Understanding to collaborate on the development of SMRs in Canada (see also Chapter on Small Modular Reactors).[1234]

Mexico



In Mexico, two General Electric (GE) reactors operate at the Laguna Verde power plant, located in Alto Lucero, Veracruz. The first unit was connected to the grid in 1989 and the second unit in 1994. In 2019, nuclear power generation decreased to 10.8 TWh, down from 13.2 TWh the previous year and providing 4.5 percent of the country's electricity, compared to 5.3 percent in 2018. The two reactors achieved an average load factor of 96.1 percent in 2018, the highest of any country that year. The power plant is owned and operated by the state utility Federal Electricity Commission (Comisión Federal de Electricidad - CFE).

The IAEA completed a long-term operational safety review of the Laguna Verde nuclear power plant in March 2019. The IAEA team has made recommendations as part of the process to extend the operating lives of the reactors, as the CFE has requested that the units be granted a

1230 - M. V. Ramana and Xiao Wei, "Ontario can phase out nuclear and avoid increased carbon emissions", *The Conversation*, 5 January 2020, see http://theconversation.com/ontario-can-phase-out-nuclear-and-avoid-increased-carbon-emissions-128854, accessed 22 March 2020.

1231 - M. V. Ramana and Xiao Wei, "Why Ontario must rethink its nuclear refurbishment plans", *The Conversation*, 6 January 2020, see http://theconversation.com/why-ontario-must-rethink-its-nuclear-refurbishment-plans-127667, accessed 22 March 2020.

1232 - Josee St-Onge, "Government casts shadow over future of Alberta solar industry", *CBC News*, 22 June 2019, see https://www.cbc.ca/news/canada/edmonton/ucp-end-rebates-solar-energy-jobs-future-industry-1.5179127; and Mike Crawley, "Doug Ford government spent $231M to scrap green energy projects", *CBC News*, 19 November 2019, see https://www.cbc.ca/news/canada/toronto/doug-ford-green-energy-wind-turbines-cancelled-230-million-1.5364815, both accessed 23 March 2020.

1233 - Seamus O'Regan, "Keynote Address", presented at the Canadian Nuclear Association – 2020 Conference, 27 February 2020, see https://www.terrestrialenergy.com/wp-content/uploads/2020/03/Keynote-Address-Minister-ORegan-CNA-Feb-27.pdf, accessed 23 March 2020.

1234 - Mickey Djuric, "Premiers Moe, Ford, Higgs to collaborate on development of nuclear reactors in Canada", *Global News*, 1 December 2019, see https://globalnews.ca/news/6241337/premiers-collaborate-nuclear-reactors/, accessed 22 March 2020.

30-year lifetime extension, to enable each unit to operate for a total of 60 years.[1235] The license renewal was granted in July 2020 to July 2050.[1236]

In 2013 the Mexican Congress began restructuring the power sector, to move away from a vertically integrated utility to enable private actors to enter the sector, for private financing for the transmission and distribution networks and eventually to enable retail competition. The role of CFE was also modified as it was unbundled into different supply, distribution and retail arms, which included a separate entity to operate Laguna Verde. According to the Wilson Centre, "The reform allows all participants in the newly created power market to compete under equal conditions to sell generation supply contracts in a competitive bidding process and gives open access to the grid. The sole exception to this new open market is nuclear power generation, which remains controlled by CFE".[1237] But in March 2019—following the election in December 2018 of President López Obrador who always opposed the 2013-reform—the Wilson Centre stated: "Mexico's energy reform is still incomplete and faces new challenges under a new Andrés Manuel López Obrador administration".[1238] Indeed, the incoming President said he would not try to "constitutionally reverse the reforms", but has sought to prioritize public utilities, and canceled renewable energy and oil auctions alike, announced a revision of CFE's contracts with renewable energy companies "because of the subsidies" and vowed to dramatically expand CFE's power generation business, "if private power companies do not boost their investment in the sector".[1239] However, the renewable energy industry has won a significant battle, when, in December 2019, a federal judge in Mexico City overturned rules that would have extended clean energy certificates meant to support post-2014 renewable projects to legacy hydro and nuclear power.[1240]

Also 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. It was further stated that each 1.4 GW-unit would be able to operate for 60 years and would each cost US$7 billion.[1241] A feasibility study for the project was to be developed and completed in 2020 and presented to the Government.[1242]

1235 - *NEI*, "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 2 June 2020.

1236 - 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 20 July 2020.

1237 - Duncan Wood, Sarah Ladislaw et al., "Mexico's New Energy Reform", Mexico Institute, Woodrow Wilson International Center for Scholars, October 2018, see https://www.wilsoncenter.org/publication/mexicos-new-energy-reform, accessed 2 June 2020.

1238 - Wilson International Center for Scholars, "The Outlook for Mexico's Energy Sector under the AMLO Administration", 5 March 2019, see https://www.wilsoncenter.org/event/the-outlook-for-mexicos-energy-sector-under-the-amlo-administration, accessed 2 August 2020.

1239 - Anthony Esposito, "Mexico's president doubles down on nationalist line: no oil auctions", *Reuters*, 8 January 2020, see https://www.reuters.com/article/us-mexico-oil-auctions/mexicos-president-doubles-down-on-nationalist-line-no-oil-auctions-idUSKBN1Z729H, accessed 2 August 2020.

1240 - José Rojo Martín, "Victory for Mexican solar as court blocks 'damaging' policy changes – reports", *PV Tech*, 3 December 2019, see https://www.pv-tech.org/news/victory-for-mexican-solar-as-court-blocks-damaging-policy-changes-reports, accessed 2 August 2020.

1241 - *Forbes Mexico*, "4 nuclear reactors under consideration by electricity commission", *Mexico News Daily*, 11 December 2019.

1242 - Arms Control Association, "The U.S. Atomic Energy Act Section 123 At a Glance", Fact Sheets & Briefs, April 2019, see https://www.armscontrol.org/factsheets/AEASection123, accessed 2 June 2020.

United States

See United States Focus.

ASIA & MIDDLE EAST

Bangladesh

The construction of Bangladesh's two inaugural nuclear reactors at Rooppur has continued over the past year, and the Government has continued to back it up with high budgetary inputs.[1243] However, construction is expected to slow due to the COVID-19 pandemic. In April 2020, Russian-based nuclear energy company, Rosatom, announced personnel working on construction sites abroad will be "given the opportunity to return" home.[1244] Numbers of local day laborers working on site had also dropped over coronavirus fears.[1245]

The two 1200-MWe VVER reactors are owned by the Bangladesh Atomic Energy Commission (BAEC), and the initial contract with Rosatom was worth US$12.65 billion.[1246] Of this amount, Russia is to provide 90 percent of the cost as state credit for the project, which is to be paid back over "the next 28 years with an 8-year grace period".[1247] Construction on Rooppur-1 and -2 began in November 2017 and July 2018, respectively.[1248]

In March 2020, Russia and Bangladesh signed an intergovernmental agreement to expand Rosatom's engagement on a "long-term basis to assist in the operation, maintenance and repair" of Rooppur-1 and -2.[1249] The agreement between Government bodies also stipulates that Russia is to supply the equipment, materials, and crew training required of the two units, and Rosatom subsidiary, TVEL JSC, is to supply the nuclear fuel.

The project's economics have been widely questioned. Earlier in 2017, a retired nuclear engineer who had been involved in advising the BAEC, argued in one of the leading English-language newspapers in Bangladesh that the country was "paying a heavy price" for BAEC not having "undertaken a large-scale programme of recruitment, and training of engineers"; he also charged that Bangladesh was buying reactors at the "unreasonable and unacceptable"

1243 - Nazmul Likhon, "Rooppur to Get Highest Budget Allocation", *Bangladesh Post*, 12 May 2020, see https://bangladeshpost.net/posts/rooppur-to-get-highest-budget-allocation-33241.

1244 - *WNN*, "COVID Impact On Construction Projects Not Yet Clear", 3 April 2020, see https://www.world-nuclear-news.org/Articles/COVID-impact-on-construction-projects-not-yet-clea, accessed 20 August 2020.

1245 - Eyamin Sajid, "Rooppur Power Plant Construction Continues as Usual", *The Business Standard*, 1 April 2020, see https://tbsnews.net/bangladesh/energy/rooppur-power-plant-construction-continues-usual-63928, accessed 20 August 2020.

1246 - *WNN*, "Bangladesh Completes Basemat of Second Rooppur Turbine Hall" 7 August 2019, see https://www.world-nuclear-news.org/Articles/Second-Rooppur-turbine-hall-basemat-completed, accessed 20 August 2020.

1247 - Fakruddin Mehedi, "Rooppur Nuclear Power Plant Unit Sale Rate Tk 3.5", *The Asian Age*, 11 April 2016, see http://dailyasianage.com/news/15846/?regenerate, accessed 20 August 2020.

1248 - IAEA, "Country Details - Bangladesh", Power Reactor Information System (PRIS) Database, 11 May 2020, see https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=BD.

1249 - *WNN*, "Russia and Bangladesh Expand Nuclear Cooperation", 18 March 2020, see https://www.world-nuclear-news.org/Articles/Russia-and-Bangladesh-expand-nuclear-cooperation, accessed 20 August 2020.

price of US$5,500/kW because its "negotiators didn't have the expertise to properly scrutinise the quoted price".[1250]

There have been reports about corruption in the construction of the nuclear plant, although these allegations largely revolve around materials for housing of plant workers and their families.[1251]

Nuclear power is projected in the Bangladesh Revised Power Sector Master Plan to account for about 4 percent of electricity generation in 2030, and there are ongoing discussions with Chinese nuclear officials from Dongfang Electric Corporation and China Nuclear Engineering & Construction Corp, about building a second plant.[1252]

However, according to a report published by the Atlantic Council even this small contribution is not necessary, and "Bangladesh can move towards a more sustainable, lower carbon future by limiting coal development, installing efficient natural gas, expanding renewables, and improving end-use energy efficiency".[1253]

Bangladesh has experienced substantial growth in renewable capacity over the last decade, increasing from roughly 0.26 GW in 2010 to 0.52 GW in 2019.[1254] While the total remains small and mostly hydropower that remained stable, the bulk of the growth stems from solar capacity installations, which expanded by a factor of nine from 0.032 GW in 2010 to 0.28 GW in 2019. Wind power capacity grew by very modest 1 MW from 2 MW to 3 MW total. Actual electrical energy generated from solar power is increasing at a 40-percent growth rate as of 2019, albeit from a low base.[1255] The expansion continues, with some financing from the World Bank. Earlier this year, in January 2020, the Electricity Generation Company of Bangladesh tendered a 50 MW solar plant; roughly US$74 million from the World Bank loan will finance this project.[1256]

China

See China Focus.

1250 - Abdul Martin, "The economics of the Rooppur Nuclear Power Plant", *The Daily Star*, 2 March 2017, see https://www.thedailystar.net/op-ed/economics/the-economics-the-rooppur-nuclear-power-plant-1369345, accessed 28 May 2020.

1251 - *The Daily Star*, "Corruption in Rooppur Nuclear Power Plant: HC seeks to know steps", 2 July 2019, see https://www.thedailystar.net/city/corruption-in-rooppur-power-plant-hc-seeks-know-steps-1765591, accessed 28 May 2020.

1252 - *NEI*, "Newcomer nations", *NEI Magazine*, 25 June 2019, see https://www.neimagazine.com/features/featurenewcomer-nation-7274233/, accessed 28 May 2020.

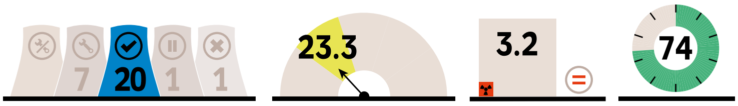
1253 - Dr Robert F. Ichord, "Transforming the power sector in developing countries: Geopolitics, poverty, and climate change in Bangladesh", Atlantic Council, 9 January 2020, see https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/transforming-the-power-sector-in-developing-countries-geopolitics-poverty-and-climate-change-in-bangladesh/, accessed 4 July 2020.

1254 - IRENA, "Renewable Capacity Statistics 2020", International Renewable Energy Agency, 2020, see https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020.

1255 - BP, "Statistical Review of World Energy 2020", June 2020, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

1256 - Syful Islam, "Bangladesh Tenders 50 MW Solar Plant", *PV Magazine International*, 2 January 2020, see https://www.pv-magazine.com/2020/01/02/bangladesh-tenders-50-mw-solar-plant/.

India



The IAEA lists India as having 22 operational nuclear power reactors, with a total net generating capacity of 6.2 GW. However, according to the WNISR criteria, some of these fall under the LTO category. The new entrant to the LTO category this year is Madras-1, which was shut down on 30 January 2018 to carry out repair work, and had not come back up as of the beginning of July 2020.[1257] The Rajasthan-1 reactor which has not generated power since 2004, was moved from LTO to "closed" in WNISR2018, as its final closure had been officially announced.[1258]

In addition to these operating reactors, seven more reactors, with a combined capacity of 4.8 GW, are under construction. These include two VVER-1000s at Kudankulam (since June and October 2017), four Pressurized Heavy-Water Reactors (PHWR), two at Kakrapar (since November 2010) and two at Rajasthan (since July and September 2011), and a Prototype Fast Breeder Reactor (PFBR), construction of which started in October 2004. One of the Kakrapar PHWRs reached first criticality in July 2020.

Nuclear power contributed 40.7 TWh of electricity in 2019, up from 35.4 TWh in 2018. The share of nuclear power in 2019 has increased slightly from 3.1 percent in 2018 to match the 2017 figure of 3.2 percent. These IAEA-PRIS numbers are somewhat different from those reported by India's Central Electricity Authority (CEA). For the period from April 2019 to March 2020, CEA records 46.4 TWh from nuclear power, higher than the corresponding figure of 37.8 TWh from April 2018 to March 2019.[1259]

In comparison, renewable energy sources, without including large hydropower plants, together generated 138.3 TWh during the period from April 2019 to March 2020, up from 126.8 TWh generated from April 2018 to March 2019.[1260] Of the generation in 2019–2020, wind and solar energy contributed 64.6 TWh and 50.1 TWh respectively. Likewise, BP records figures of 46.3 TWh, 63.3 TWh, and 45.2 TWh for solar, wind, and nuclear energy in the calendar year 2019.[1261] Thus, both wind and solar power have larger shares of overall electricity generation than nuclear power. This was to be expected, given the high rates of growth in solar and wind energy. According to the International Renewable Energy Agency (IRENA), installed solar capacity has increased from 9.6 GW in 2016 to 34.8 GW in 2019, and wind capacity from 28.7 GW in 2016 to 37.5 GW in 2019.[1262]

1257 - NPCIL, "Madras Atomic Power Station (MAPS) – Operating Performance", May 2020, see https://www.npcil.nic.in/content/324_1_OperatingPerformance.aspx; and PIB, "Nuclear Power Plants", Press Information Bureau, Government of India, 11 March 2020, see https://pib.gov.in/newsite/PrintRelease.aspx?relid=200062; and IANS, "Madras Atomic Power Station's Unit-1 yet to restart", *Outlook India*, 5 December 2019, see https://www.outlookindia.com/newsscroll/madras-atomic-power-stations-unit1-yet-to-restart/1678018, all accessed May 2020.

1258 - *Deccan Herald*, "End of the road for RAPS 1", 6 September 2014, see http://www.deccanherald.com/content/429550/end-road-raps-1.html, accessed 16 June 2016.

1259 - CEA, "Executive Summary on Power Sector March 2020", Central Electric Authority, Ministry of Power, Government of India, March 2020, see http://www.cea.nic.in/reports/monthly/executivesummary/2020/exe_summary-03.pdf, accessed 16 May 2020.

1260 - CEA, "Renewable Energy Project Monitoring Division: March 2020", Central Electric Authority, Sub Report-1, 2020, see http://www.cea.nic.in/reports/monthly/renewable/2020/renewable-03.pdf, accessed 16 May 2020.

1261 - BP, "Statistical Review of World Energy 2020", June 2020, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 17 June 2020.

1262 - IRENA, "Renewable Capacity Statistics 2020", International Renewable Energy Agency, 2020, see https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020, accessed 24 April 2020.

The divergence between a growing renewable energy sector and a relatively stagnant nuclear sector is expected to increase in coming years, and this is openly acknowledged by the Government of India. The reason for the divergence was explained by the Parliamentary Standing Committee on Science & Technology, Environment, Forests and Climate Change in March 2020 when it contrasted the "crashing" price of solar power with the costs of nuclear power that it described as "going up due to greater concerns on safety, following the Fukushima disaster in May 2011".[1263] A Task Force set up by the Department of Economic Affairs of India's Ministry of Finance to, among other things, "identify technically feasible and financially/ economically viable infrastructure projects that can be initiated in fiscal years 2020 to 2025",[1264] foresees renewable capacity (not including large hydropower projects) going from 22 percent of the total installed electrical capacity, as of March 2019, to 39 percent by 2025, or an increase of over 250 percent over today's installed capacity.[1265] In contrast, nuclear stays more or less constant at 2 percent of installed capacity. This, despite, an ambitious goal of commissioning seven new reactors during this five-year period.

The nuclear construction goal is unlikely to be met given the earlier history of missed targets,[1266] and how slow the current set of reactor construction projects are going. Although the Government has "accorded administrative approval and financial sanction" for constructing ten 700-MW PHWRs at various sites around the country and two more VVER-1000s at Kudankulam (Kudankulam-5 and -6), construction is yet to begin on any of these.[1267] No new reactor has been connected to the grid since 2018, and at least five of the seven reactor construction projects underway are delayed. Initially, the two PHWRs at Kakrapar were to be commissioned in 2015 and the two at Rajasthan, in late 2016.[1268] According to the Indian government, as of March 2020, the anticipated dates of commissioning are October 2020 and September 2021 for Kakrapar-3 and -4 respectively, and March 2022 and March 2023 for Rajasthan-7 and -8 respectively.[1269] In other words, even if these current expectations were met, construction time for these projects would have more than doubled.

The Prototype Fast Breeder Reactor (PFBR) has been the most delayed project for some years now. It was supposed to be completed by 2010 but its startup date has been repeatedly pushed back. In March 2020, the Parliamentary Standing Committee on Science & Technology, Environment, Forests and Climate Change outlined the "hope" that the Department of Atomic Energy (DAE) will be in a position to commission the PFBR at Kalpakkam by the end of

1263 - Department-related Parliamentary Standing Committee on Science & Technology, Environment, Forests and Climate Change, "Demands for Grants (2020-2021) of the Department of Atomic Energy (Demand No. 03)", Report No. 326, Parliament of India, Rajya Sabha Secretariat, 6 March 2020, see https://rajyasabha.nic.in/rsnew/Committee_site/Committee_File/ReportFile/19/126/326_2020_3_15.pdf, accessed 16 May 2020.

1264 - Department of Economic Affairs, "National Infrastructure Pipeline—Volume I", Report of the Task Force, Ministry of Finance, Government of India, 2020, see https://dea.gov.in/sites/default/files/Report%20of%20the%20Task%20Force%20National%20Infrastructure%20Pipeline%20%28NIP%29%20-%20volume-i_1.pdf, accessed 30 August 2020.

1265 - Department of Economic Affairs, "National Infrastructure Pipeline—Volume II", Report of the Task Force, Ministry of Finance, Government of India, 2020, see https://dea.gov.in/sites/default/files/Report%20of%20the%20Task%20Force%20National%20Infrastructure%20Pipeline%20%28NIP%29%20-%20volume-ii_0.pdf, accessed 16 May 2020.

1266 - M. V. Ramana, "The Power of Promise: Examining Nuclear Energy in India", *Penguin India*, 2012.

1267 - PIB, "Nuclear Power Plants", Press Information Bureau, Department of Atomic Energy, Government of India, 11 March 2020, see https://pib.gov.in/newsite/PrintRelease.aspx?relid=200062, accessed 16 May 2020.

1268 - MoSPI, "37th Report on Mega Projects (Rs. 1000 Crores and above) June, 2012", Ministry of Statistics and Programme Implementation, 2012.

1269 - Jitendra Singh, "Unstarred Question No. 1602: Commissioning of heavy water reactor at Kakrapar Nuclear Plant", Parliament of India, Rajya Sabha, March 2020.

2021,[1270] a timeline that accords with other recent statements.[1271] The Committee acknowledges the lengthy delay on this project, but advocates for completion, suggesting the PFBR will "transform" India's nuclear energy program.

That "transformation" might take longer than India's nuclear establishment promised. In the latest annual report published by Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), the organization in charge of building and operating the PFBR, the Chairman admits that within the organization "a re-think is being done" about the capacity of the next fast breeder reactors and "based on the on-going difficulties and experience generated during the entire on-going commissioning phase of PFBR, it is being deliberated whether for the purpose of standardization it may be prudent to retain them as 500 MWe units" in contrast to earlier proposals to build a design capable of generating 600 MWe.[1272] The on-going difficulties during the commissioning phase refers to numerous problems involving various components of the PFBR, including electro-magnetic pumps, fueling machinery, and secondary sodium pumps. In addition to considering lowering the power level of future FBRs, the annual report also admits that "construction of these reactors is expected to commence, only after the power operation of PFBR, so as to ensure availability of adequate performance feedback /data from PFBR and correspondingly bringing about suitable incorporation of required design changes in the proposed FBRs".[1273] In contrast, the previous annual report had asserted that "construction of these reactors is expected to commence in 2021 by which time, adequate performance feedback on full power operation from PFBR is expected to be available, for factoring in the proposed 600 MWe designs".[1274]

The projected cost of the PFBR has also risen, from the initially anticipated Rs.34.9 billion (US$463 million) to, first, Rs.56.7 billion (US$752 million), to currently Rs.68.4 billion (US$907 million).[1275] Other projects have become more expensive too.[1276] Kakrapar-3 and -4 are now projected to cost Rs.165.8 billion (US$2.2 billion), up from Rs.114.6 billion (US$1.5 billion), while Rajasthan-7 and -8 are now projected to cost Rs.170.8 billion (US$2.3 billion), up from Rs.123.2 billion (US$1.7 billion).[1277]

The increase in construction cost is leading to difficulty in selling its power. The Nuclear Power Corporation of India (NPCIL) sent a formal communication to the state of Gujarat, where the Kakrapar reactor site is located, seeking an increase in tariff, from Rs.3.34/kWh to

1270 - Department-related Parliamentary Standing Committee on Science & Technology, Environment, Forests and Climate Change, "Demands for Grants (2020-2021) of the Department of Atomic Energy (Demand No. 03)", Parliament of India, Rajya Sabha Secretariat, March 2020.

1271 - Jitendra Singh, "Unstarred Question No. 1602: Commissioning of Heavy Water Reactor at Kakrapar Nuclear Plant", Parliament of India, Rajya Sabha, March 2020.

1272 - BHAVINI, "16th Annual Report 2018-19", Bharatiya Nabhikiya Vidyut Nigam Limited, 2019, see https://bhavini.nic.in/writereaddata/AnnualReport/42.pdf, accessed 12 July 2020.

1273 - Ibidem, p.2.

1274 - BHAVINI, "15th Annual Report 2017-18", Bharatiya Nabhikiya Vidyut Nigam Limited, September 2018, see https://bhavini.nic.in/writereaddata/AnnualReport/40.pdf, accessed 12 July 2020.

1275 - MoSPI, "Flash Report on Central Sector Projects (Rs. 150 crore and above) December 2019", Ministry of Statistics and Programme Implementation, 2019.

1276 - As of 1 July 2020, the conversion rate to US dollars is around Rs.75 per US dollar. All of these cost indications remain extremely low compared to other countries. While the lack of independent assessments of these cost calculations is an issue, it is clear that incomparably lower labor costs dramatically change overall costs if compared to nuclear projects elsewhere. Also, the PFBR costs are in mixed-year Rupees and so directly converting it into other currencies using one conversion rate is rather misleading.

1277 - Ibidem, Table 30.

Rs.5.31/kWh (US$0.05 to US$0.07 per kWh).[1278] The state of Gujarat is to purchase 50 percent of the power output when the reactor commences operations.[1279] After being notified of the intention to increase tariff, the state reportedly asked the central Government to intervene and lower the tariff, pointing out that the average purchase price for non-renewable based power in the previous year was Rs.3.98/kWh (US$0.06/kWh). For comparison, the three successful bids in the March 2020 solar power auction were Rs.2.61, Rs.2.63, and Rs.2.64/kWh,[1280] clear evidence of the disjuncture between the evolving costs of nuclear and solar power that the Parliamentary Committee spoke about in March 2020.[1281] The higher rate was particularly problematic for Gujarat because nuclear reactors have what is called "must run" status.[1282]

The next set of two 700-MW PHWRs are at Gorakhpur in the northern state of Haryana, which was selected in June 2007; at that time, a high-level government official had stated that "work to set up a nuclear power plant in the state would commence soon".[1283] More than a dozen years later, a similar promise was made in October 2019 by a senior NPCIL official who told a journalist that first pour of concrete was "expected very soon".[1284] Although concrete pouring has not commenced the project is listed as "under construction" by the Department of Atomic Energy.[1285] International definition of construction start is the beginning of the concreting of the base slab of the reactor building. As of July 2020, the IAEA's PRIS database does not list any reactors as under construction at Gorakhpur.

According to the same NPCIL official, the design of the reactors to be constructed at Gorakhpur was one that NPCIL had made "the standard design".[1286] However, at Rs.206 billion (US$2.7 billion), its projected cost is nearly 25 percent higher than Rs.165.8 billion (US$2.2 billion), the revised cost of the first of a kind (FOAK) version of the same reactor design, the 700-MW PHWRs at Kakrapar-3 and -4.[1287] And since even the latter is already twice as expensive as the cost of solar power, electricity from this "standard design" PHWR will likely be thrice or more as expensive as solar power. A similar increase is also observed in estimated costs of imported VVERs from Russia, with Kudankulam-3 and -4 being more

1278 - Anupam Chatterjee, "Delay impact: Gujarat seeks tariff cut for power from Kakrapar N-units", *Financial Express*, 24 October 2019, see https://www.financialexpress.com/economy/delay-impact-gujarat-seeks-tariff-cut-for-power-from-kakrapar-n-units/1744478/, accessed 14 May 2020.

1279 - Rishi Banerji, "Construction of nuclear power plant begins at Kakrapar", *Daily News & Analysis*, 29 November 2010.

1280 - Rakesh Ranjan, "Juniper Green, Vena Energy, and Tata Power Win Gujarat's 500 MW Solar Auction", *Mercom India*, 18 March 2020, see https://mercomindia.com/gujarat-500-mw-solar-auction/, accessed 14 May 2020.

1281 - Department-related Parliamentary Standing Committee on Science & Technology, Environment, Forests and Climate Change, "Demands for Grants (2020-2021) of the Department of Atomic Energy (Demand No. 03)", Parliament of India, Rajya Sabha Secretariat, March 2020.

1282 - Anupam Chatterjee, "Delay Impact: Gujarat Seeks Tariff Cut for Power from Kakrapar N-Units", *Financial Express*, 24 October 2019.

1283 - ENS, "Work on nuclear power plant to start soon: CS", *Indian Express*, 21 June 2007.

1284 - Ritu Sharma, "First Concrete Pour for Haryana's Nuclear Reactor expected soon: NPCIL Technical Director", *Nuclear Asia*, 29 October 2019, see https://www.nuclearasia.com/news/first-concrete-pour-haryanas-nuclear-reactor-expected-soon-npcil-technical-director/3209/, accessed 17 May 2020.

1285 - PIB, "Nuclear Power Plants", Press Information Bureau, Department of Atomic Energy, Government of India, 11 March 2020.

1286 - Ritu Sharma, "First Concrete Pour for Haryana's Nuclear Reactor Expected Soon: NPCIL Technical Director", *Nuclear Asia*, 29 October 2019.

1287 - PIB, "Nuclear Power Plants", Press Information Bureau, Department of Atomic Energy, Government of India, 11 March 2020.

expensive than the first two units, and Kudankulam-5 and -6 being nearly 25 percent more expensive than Kudankulam-3 and -4.[1288]

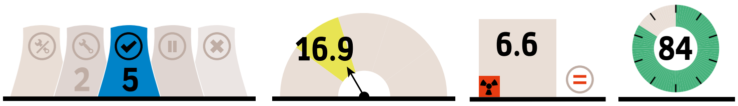
Officially, there are still plans to import reactors from the United States and France for the Kovvada and Jaitapur sites. These were first proposed as part of the US-India nuclear deal that was negotiated between 2005 and 2008.[1289] Although there are mounting concerns over their costs, these plans get dusted off every time there is a visit from a head of state from these two countries. The latest such effort happened in the case of the Kovvada site when President Donald Trump visited in February 2020; at the end of the visit, a joint statement was released, which merely encouraged "the Nuclear Power Corporation of India Limited and Westinghouse Electric Company to finalize the techno-commercial offer for the construction of six nuclear reactors in India at the earliest date".[1290] If these reactors are constructed, it has been estimated that the tariffs for electricity from these could be around Rs.25/kWh (US$0.33/kWh), about eight to ten times the cost of solar power.[1291]

The performance of the last major imported reactors operating in India, Kudankulam-1 and -2, has been poor. For the past three years, NPCIL records an average capacity factor of around 54 percent and 44 percent for the two reactors respectively.[1292] Kudankulam-1 and -2 had load factors of 59.6 percent and 58.2 percent in 2019, and cumulative load factors of 26.6 percent and 41.4 percent respectively. Kudankulam nuclear power plant was also the site of the first publicly acknowledged cyber-attack on a nuclear power plant in India.[1293]

Iran

See Middle East Focus – Section on Iran.

Pakistan



Pakistan operates five nuclear reactors with a combined capacity of 1.3 GW.[1294] Nuclear electricity production in Pakistan has decreased slightly from 2018 to 2019, from 9.3 TWh in 2018 to 9.1 TWh in 2019. The share of electricity from nuclear power plants in 2019 was 6.6 percent, down from 6.8 percent in 2018. The slight decrease appears to be primarily because the first unit of the Karachi nuclear power plant (Kanupp-1), that was commissioned

1288 - Ibidem.

1289 - Prerna Gupta and M. V. Ramana, "A Decade After the Nuclear Deal", *The India Forum*, 3 April 2019, see https://www.theindiaforum.in/article/decade-after-nuclear-deal, accessed 17 May 2020.

1290 - Ministry of External Affairs, "Joint Statement: Vision and Principles for India-U.S. Comprehensive Global Strategic Partnership", Government of India, 25 February 2020, see https://mea.gov.in/bilateral-documents.htm?dtl/32421/Joint_Statement_Vision_and_Principles_for_IndiaUS_Comprehensive_Global_Strategic_Partnership, accessed 26 February 2020.

1291 - M.V. Ramana and Suvrat Raju, "Pushing the wrong energy buttons", *The Hindu*, 3 March 2020, see https://www.thehindu.com/opinion/op-ed/pushing-the-wrong-energy-buttons/article30965454.ece, accessed 22 April 2020.

1292 - NPCIL, "Operating Performance: Kudankulam Atomic Power Project", Nuclear Power Corporation of India Limited, Department of Atomic Energy, March 2020, see https://www.npcil.nic.in/content/320_1_OperatingPerformance.aspx, accessed 17 May 2020.

1293 - *ETGovernment.com*, "NPCIL Accepts Cyber Attack on Kudankulam Nuclear Power Plant", 30 October 2019, see https://government.economictimes.indiatimes.com/news/secure-india/npcil-accepts-cyber-attack-on-kudankulam-nuclear-power-plant/71820813, accessed 22 April 2020.

1294 - IAEA, "Power Reactor Information System (PRIS) Database", see http://www.iaea.org/programmes/a2/, accessed 4 May 2020.

in 1972, operated with a low capacity factor, which in 2019 was a mere 4.9 percent. Some years back, it was reported that the reactor was scheduled for decommissioning in 2019.[1295] But it now appears that the reactor will continue to operate until 2021.[1296]

At the same site, the China National Nuclear Corporation (CNNC) continued building two Hualong One reactors. In April 2020, the containment building of the first of these units, Kanupp-2, was completed.[1297] Construction of this unit started in 2015 and it is scheduled for commercial operation in 2021. Construction of the sister unit, Kanupp-3, started in 2016 and it is scheduled for commercial operation in 2022. *Power Technology* reports that "more than 80 percent of the estimated project cost is being financed through a loan from China's state-owned Export-Import (Exim) Bank".[1298] Elsewhere, it is reported that Exim Bank has invested "over $6.6 billion over three phases".[1299]

In parallel, Pakistan has been rapidly expanding its renewable energy capacity, in particular solar energy and wind energy. Over the last five years, total renewable capacity in Pakistan has grown nearly 40 percent, climbing from 7.9 GW in 2014 to just under 13 GW in 2019.[1300] Wind and solar capacity have grown from around 0.2 GW in 2014 each to 1.2 GW and 1.3 GW respectively in 2019. Wind's share of electricity generation in the country reached 3.5 percent whereas solar was just under 1 percent.[1301] In November 2019, Pakistan's Minister of Economic Affairs announced that the country aims to add an additional 7 to 8 GW of renewable power capacity within the next four years.[1302] The renewable sector is currently worth US$40 billion in investment opportunities, according to Pakistan's Minister for Power Division.[1303] He also stated that US$700 million in investment funding was already "pouring in 12 wind energy projects".[1304] The attractiveness of the renewable energy sector in Pakistan is underscored by reports that the Denmark-based wind turbine manufacturer, Vestas, is considering establishing a wind turbine factory in the country.[1305]

1295 - Hussain Ahmad Siddiqui, "Moving forward", *The News International*, 2016, see https://www.thenews.com.pk/magazine/money-matters/137321-Moving-forward, accessed 11 May 2020.

1296 - Tasneem Fatima, "Characterization of KANUPP Irradiated Fuel Bundles", KANUPP, Pakistan Atomic Energy Commission, 12 November 2019, presented at the "Technical Meeting on Spent Fuel Characterization for Management of Spent Fuel in the Back End of the Fuel Cycle", IAEA, 12–14 November 2019, see https://nucleus.iaea.org/sites/connect/SFMpublic/TM%20on%20Spent%20Fuel%20Characterization%20for%20the%20Manageme/Fatima_KANUPP.pdf, accessed 10 May 2020.

1297 - *WNN*, "Karachi 2 Containment Building Completed", 16 April 2020, see https://www.world-nuclear-news.org/Articles/Karachi-2-containment-building-completed, accessed 6 May 2020.

1298 - *Power Technology*, "Karachi Nuclear Power Plant (KANUPP) Expansion", 2020, see https://www.power-technology.com/projects/karachi-nuclear-power-plant-expansion/, accessed 6 May 2020.

1299 - Merlin Linehan, "How Chinese Financing is Fueling Megaprojects Around the World", *Rising Powers*, 18 January 2020, see https://rising-powers.com/how-chinese-financing-is-fueling-megaprojects-around-the-world/, accessed 11 May 2020.

1300 - IRENA, "Renewable Capacity Statistics 2020", International Renewable Energy Agency, 2020, see https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020, accessed 24 April 2020.

1301 - BP, "Statistical Review of World Energy 2020", June 2020, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 17 June 2020.

1302 - *The Express Tribune*, "Pakistan Planning to Add 8,000MW of Renewable Energy to National Grid", 21 November 2019, see https://www.thenews.com.pk/print/571971-government-eyes-8-000mw-of-renewable-energy, accessed 10 May 2020.

1303 - *Daily Times*, "Up to 20,000MW renewable energy to be added to system by 2030: Omar Ayub", 21 November 2019, see https://dailytimes.com.pk/504071/minister-says-cost-of-electricity-will-decrease-with-implementation-of-alternative-energy-policy/, accessed 11 May 2020.

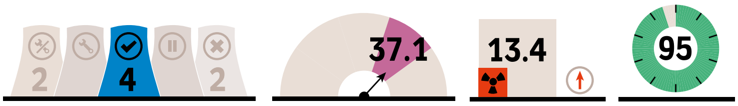
1304 - *The Express Tribune*, "'$700m Investment In Pakistan's Power Sector Under Way", 20 November 2019, see https://tribune.com.pk/story/2103479/1-700m-investment-power-sector-way-omar/, accessed 6 May 2020.

1305 - Reve, "Wind Turbines Manufacturer Vestas Studies its Implementation in Pakistan", 8 February 2020, see https://www.evwind.es/2020/02/08/wind-turbines-manufacturer-vestas-starts-factory-in-pakistan/73483, accessed 6 May 2020.

South Korea

See South Korea Focus.

Taiwan



Taiwan has four operating reactors at Kuosheng (Guosheng) and Maanshan, all owned by Taipower, the state-owned utility monopoly.[1306] In 2019, there was 31.1 TWh of nuclear generation, 13.4 percent of the nation's electricity, compared to 26.6 TWh or 11.4 percent in 2018. Nuclear generation reached its maximum share of 41 percent in 1988.

In terms of energy policy and the future of nuclear power in Taiwan, the most significant development during the past year was the 11 January 2020 landslide re-election of President Tsai Ing-wen of the Democratic Progressive Party (DPP).[1307] Elected for a second term, President Tsai secured 57.1 percent of the vote. The DPP also retained its majority in the legislative assembly. President Tsai was first elected in May 2016. Her party remains committed to the nuclear phase-out by 2025, introduced in her first term, while transitioning the energy economy to renewables.

The re-election of President Tsai is a major setback for those in Taiwan seeking to prevent the phase-out of nuclear power and the energy transition to renewable energy. The rival Chinese Nationalist Party (KMT) and its presidential candidate, Han Kuo-yu, had strongly opposed President Tsai's energy policy, calling for a life extension of existing reactors and the construction of new plants.[1308]

Historical public opposition to nuclear power in Taiwan dramatically escalated during and in the months following the start of the Fukushima Daiichi accident and 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.[1309] On 12 January 2017, the Electricity Act Amendment completed and passed its third reading in the legislature, setting in place the mechanisms for Taiwan's energy transition, including nuclear phase-out.[1310] The law also gives priority to distributed renewable energy generation, by which its generators will be given

1306 - Atomic Energy Council, "NPP Real-time Operating Status", 9 June 2019, see https://www.aec.gov.tw/english/nuclear/index11.php, accessed 10 June 2020.

1307 - *Taipei Times*, "2020 Elections: Tsai wins by a landslide", 12 January 2020, see https://www.taipeitimes.com/News/front/archives/2020/01/12/2003729107, accessed 10 June 2020.

1308 - *Taipei Times*, "Han, nuclear fans lie about wind", 5 January 2020, see https://www.taipeitimes.com/News/editorials/archives/2020/01/05/2003728728, accessed 10 June 2020; and *Nucleonics Week*, "Taiwan election returns anti-nuclear president to office", 6 February 2020.

1309 - 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 9 June 2019.

1310 - 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 9 June 2019.

preferential rates, and small generators will be exempt from having to prepare operating reserves. The monopoly of the state-run Taipower will also be terminated.[1311]

To reach its renewable energy goals of 20 percent of the nation's generation by 2025, approximately 27 GW of new offshore wind and solar capacity will be required.[1312] Between 2018-19, the Ministry of Economic Affairs (MOEA) awarded grid capacity to nine developers for 14 offshore wind projects, with 738 MW operating capacity by 2020 and 4,762 MW between 2021 and 2025.[1313] The attractive feed-in tariffs offered for offshore have attracted overseas companies.[1314] In March 2020, Orsted announced that it has committed NT$380 billion (US$12.5 billion) in total capital expenditure for off shore wind projects in Taiwan, with a capacity of 2.4 GW.[1315] Taiwan's overall target is for 5.7 GW offshore wind power by 2025 and an additional 10 GW by 2035.[1316] In the case of solar PV, the target is for 20 GW by 2025, with 4.3 GW installed as of December 2019[1317] (compared with 2.24 GW in September 2018).[1318] A total of 2.25 GW of solar PV is planned for deployment in 2020. In February 2020, it was reported that Taiwan was on track to meet its 2025 solar PV target.[1319]

Reactor Closures

As reported in WNISR 2019, Taipower announced the closure of Chinshan Unit 1 on 5 December 2018. Chinshan-2 which remained shut down from June 2017 was officially closed on 15 July 2019, when its 40-year operating license expired. Both reactors at Chinshan are Mark 1 BWRs, which began operation in 1977 and 1978 respectively. On 16 July 2019, the AEC issued the Decommissioning Permit for the Chinshan nuclear plant in accordance with the "Nuclear Reactor Facilities Regulation Act".[1320] (See Table 19 for details).

The next reactors scheduled for closure are the two BWR Units at Kuosheng (Guosheng), both of which will take place during the second four-year term of President Tsai. The 985-MW Kuosheng Unit 1 is planned for shutdown in March 2021. This is nine months before the end

1311 - *The China Post*, "Lawmakers OK wide-ranging amendments to Electricity Act", 12 January 2017, see https://chinapost.nownews.com/20170112-14213, accessed 10 June 2020.

1312 - Miaojung Lin and Lianting Tu, "Taiwan Lays Plans for $59 Billion in Renewable-Energy Finance", *Bloomberg*, 18 June 2017, see https://www.bloomberg.com/news/articles/2017-06-18/taiwan-lays-plans-for-59-billion-in-renewable-energy-finance, accessed 10 June 2020.

1313 - Bureau of Energy, "Offshore wind auction winners announced! 2 winners with 4 projects will provide 1,664 MW by 2025", Ministry of Enconomic Affairs, Press Release, 26 July 2018, see https://www.moeaboe.gov.tw/ECW/english/news/News.aspx?kind=6&menu_id=958&news_id=16111, accessed 28 July 2020.

1314 - Heidi Vella, "Taiwan: pursuing a new green energy revolution in the East", *Power Technology*, 5 November 2018, see https://www.power-technology.com/features/taiwan-pursuing-new-green-energy-revolution-east/, accessed 10 June 2020.

1315 - *Taipei Times*, "Orsted weighing nearly US$13bn in local projects", 27 March 2020, see https://www.taipeitimes.com/News/biz/archives/2020/03/27/2003733433, accessed 10 June 2020.

1316 - Ibidem.

1317 - Asia-Power, "Taiwan's solar PV installations could hit 20GW by 2025", 25 February 2020, see https://asian-power.com/power-utility/news/taiwans-solar-pv-installations-could-hit-20gw-2025#:~:text=Taiwan%20could%20ramp%20up%20its,generation%20capacity%20of%204.3GW, accessed 10 June 2020.

1318 - Rhea Tsao, "Will Taiwan meet its 20 GW solar goal by 2025?", PV Magazine, 7 September 2018, see https://www.pv-magazine.com/2018/09/07/will-taiwan-meet-its-20-gw-solar-goal-by-2025/, accessed 9 July 2019.

1319 - *Power-Technology*, "Taiwan marching towards record installation of 20GW solar PV by 2025", 24 February 2020, see https://www.power-technology.com/comment/taiwan-marching-towards-record-installation-of-20gw-solar-pv-by-2025/, accessed 10 June 2020.

1320 - AEC, "The Atomic Energy Council Issued the Decommissioning Permit for Chinshan Nuclear Power Plant on July 12, 2019", Press Release, Atomic Energy Council, 12 July 2019, see https://www.aec.gov.tw/, accessed 26 July 2019.

of its operating license on 27 December as a result of inadequate spent fuel pool capacity. The Kuosheng Unit 2 is planned for closure on 15 March 2023. Maanshan's PWR Unit 1 and Unit 2 are scheduled for closure on 26 July 2024 and 17 May 2025, respectively.

Table 19 · Scheduled Closure Dates for Nuclear Reactors in Taiwan 2018–2025

Reactor	Type	Capacity MW[a]	Grid Connection (dd/mm/yyyy)	Date of Cessation of Operation (dd/mm/yyyy)[b]	Spent Fuel Storage Status	
					Capacity (Assembly)	Storage Inventory Fuel Assembly
Chinshan-1	BWR	604	16/11/1977	05/12/ 2018	3,083	3,074
Chinshan-2	BWR	604	19/12/1978	15/07/2019	3,083	3,076
Kuosheng-1	BWR	948	21/05/1981	27/12/ 2021	4,838	4,688
Kuosheng-2	BWR	948	29/06/1982	14/03/ 2023	4,838	4,540
Maanshan-1	PWR	890	09/05/1984	26/07/ 2024	2,160	1,581
Maanshan-2	PWR	890	25/02/1985	17/05/ 2025	2,160	1,593
Total: 4 operating Reactors / 2 Closed: 4 884 MW					**20,162**	**18,552**

Sources: Taipower, 2017, AEC[1321], WNISR, 2020.

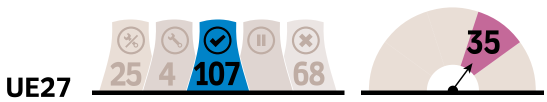
Note

BWR = Boiling Water Reactor; PWR = Pressurized Water Reactor.

a – Design Capacity

b – Official closing dates for Chinshan-1 & Chinshan-2

EUROPEAN UNION (EU27-28)



About half of the European Union (EU28)[1322] member states have gone through three nuclear construction waves (see Figure 62)—two small ones in the 1960s and the 1970s and a larger one in the 1980s (mainly in France).

The region has not had any significant nuclear building activity since the 1990s. There were no construction starts in Western Europe since 1991 prior to Olkiluoto-3 (2005) and Flamanville-3 (2007). Only three reactors were connected to the EU-grid over the past 20 years, all in Eastern Europe (two in the Czech Republic and one in Romania), none since Cernavoda-2 started up in Romania in 2007. Two reactors are under construction in Slovakia (Mochovce-3 and -4), where construction started in 1985.

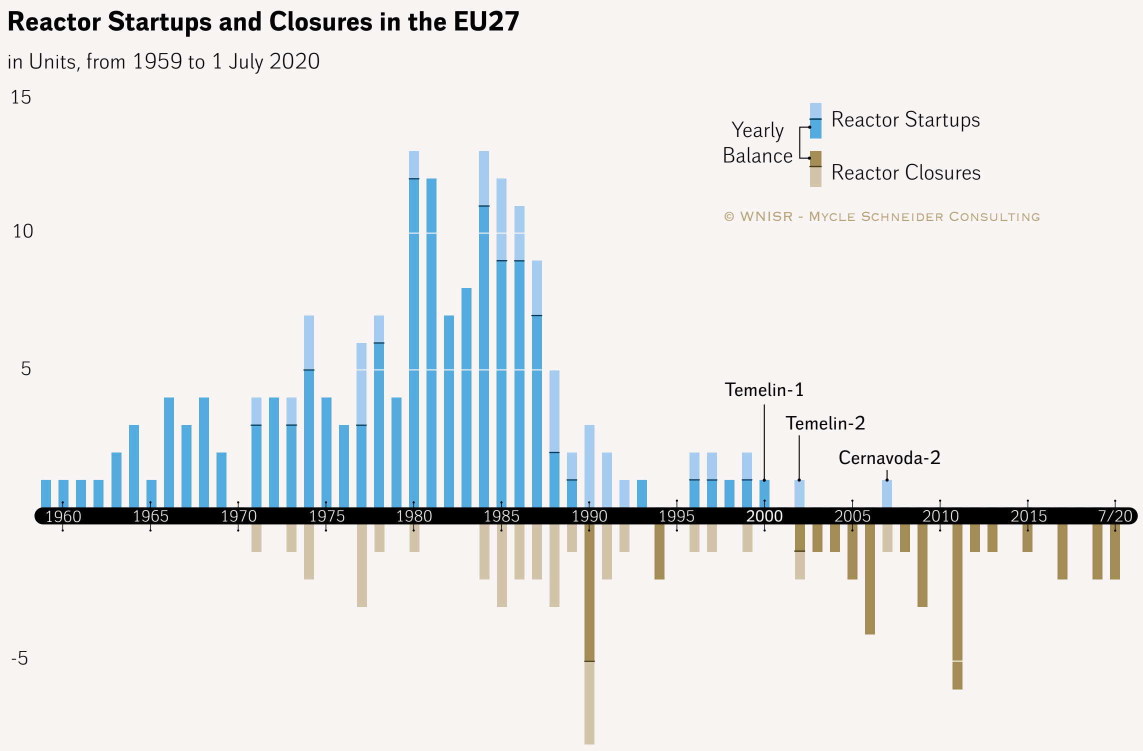
Four reactors were closed in the EU since WNISR2019, two in France and one each in Sweden and Germany. The total number of permanently closed units in the European Union is 68 (almost nine in ten located in Western Europe, of which 30 in Germany). With U.K. leaving the EU, there are 30 less closed reactors in the EU. As of 1 July 2020, the remaining 27 countries

1321 - Atomic Energy Council, "Spent Fuel Storage Status (31 July 2020)", Atomic Energy Council, Atomic Energy Council, 28 August 2020, see https://www.aec.gov.tw/english/Radioactive-Waste-Management/Spent-Fuel-Management-148.html, accessed 28 August 2020.

1322 - The U.K. left the E.U. on 31 January 2020. We are considering annual data until the end of 2019 including the U.K. (EU28) and the status as of mid-2020 without the U.K. (EU27).

in the EU operated 107 reactors, about one-fourth of the world total, 29 less than the historic maximum of 136 units in 1989 (see Figure 63).

Figure 62 · Nuclear Reactors Startups and Closures in the EU27 1959–1 July 2020



Sources: WNISR, with IAEA-PRIS, 2020

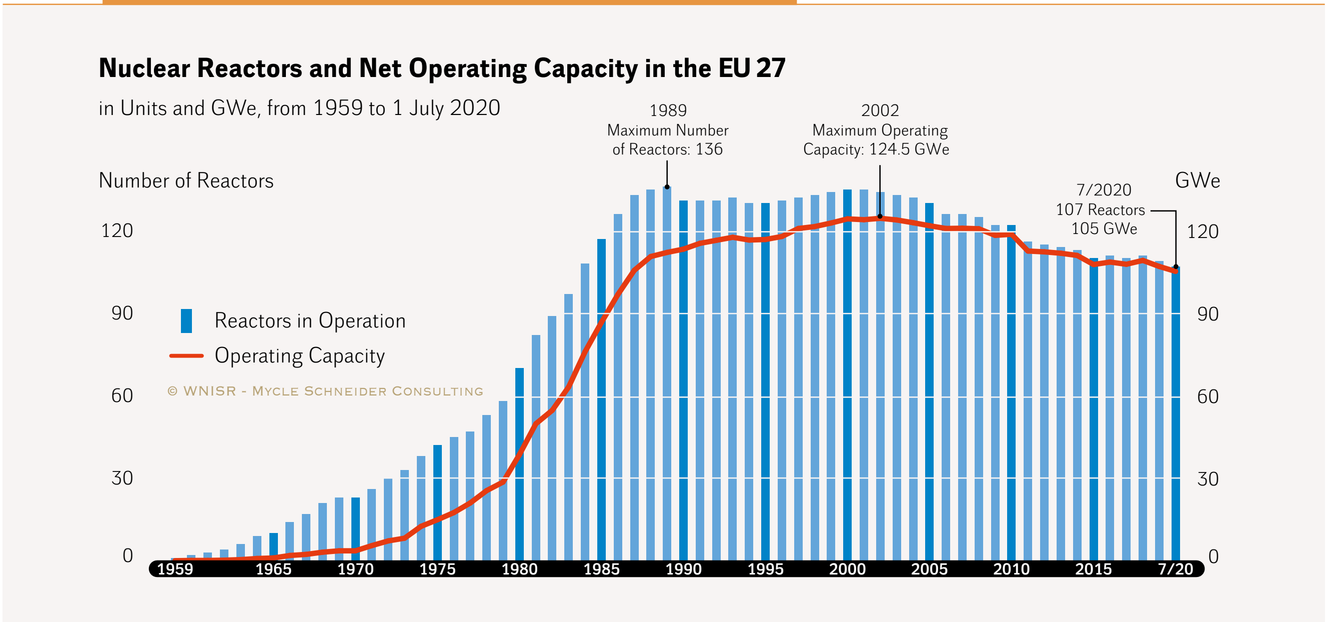
The vast majority of the operating facilities, 88 units or over 80 percent, are located in seven of the western countries, and only 19 are in the six newer member states with nuclear power.

In the EU28, in 2019, nuclear plants have generated 783 TWh, stable (-0.5 percent) compared to the previous year. While the nuclear's share in net power production is not yet available, BP indicates a stable 25.6 percent share in gross generation (25.3 percent in 2018).[1323]

In the absence of any significant delivering new-build program, the average age of nuclear power plants keeps increasing and at mid-2020 stands at 35 years (see Figure 64). The age distribution shows that now over 84 percent—90 of 107—of the EU's operating nuclear reactors have been in operation for 31 years and beyond.

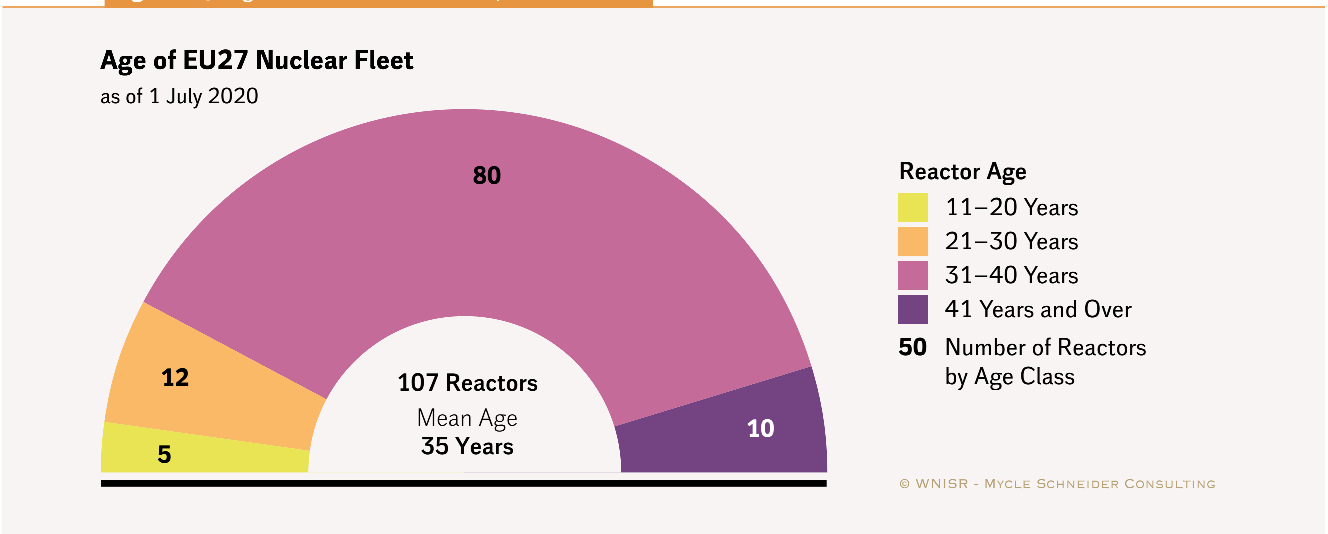
1323 - BP, "Statistical Review of World Energy–Workbook", Statistics Work Book, June 2020, op. cit.

Figure 63 · Nuclear Reactors and Net Operating Capacity in the EU27



Sources: WNISR, with IAEA-PRIS, 2020

Figure 64 · Age Distribution of the EU27 Reactor Fleet



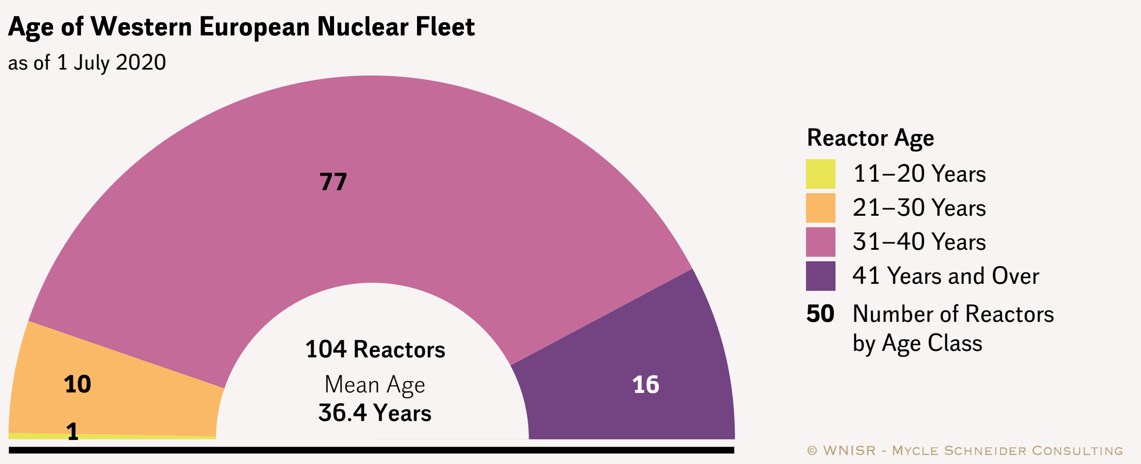
Sources: WNISR, with IAEA-PRIS, 2020

WESTERN EUROPE

As of 1 July 2020, 104 nuclear power reactors operated in Western Europe (including U.K. and Switzerland), 56 units fewer than in the peak 1988/89. There are also three reactors in LTO in the U.K. In addition to the four reactors closed in the EU since WNISR2019, one reactor was closed in Switzerland (the 48-year old unit at Mühleberg).

With the U.K. and Switzerland both operating three reactors over 41 years old—of which the 51-year old Beznau reactor—the average age of operating reactors in Western Europe reaches 36.4 years.

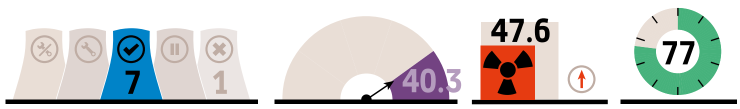
Figure 65 · Age Distribution of the Western European Reactor Fleet (incl. Switzerland and the U.K.)



Sources: WNISR, with IAEA-PRIS, 2020

Four reactors are currently under construction, two in the U.K (Hinkley Point C-1 and C-2) and one each in Finland (Olkiluoto-3) and France (Flamanville-3). All are European Pressurized Water Reactors (EPR) and all are many years behind their initial schedule and billions of Euros over budget (details are discussed in other chapters of the report).

Belgium



Belgium operates seven pressurized-water reactors that have generated 27.3 TWh in 2018, almost one-third less than the 40.2 TWh in 2017. Production greatly recovered in 2019 to reach 41.4 TWh, that is a 52-percent increase over the previous year, still somewhat below a maximum of 46.7 TWh twenty years earlier, in 1999. Nuclear power contributed 47.6 percent of Belgium's electricity in 2019, a jump of 8.6 percentage points over 2018, while the maximum was 67.2 percent in 1986.

Due to continuous technical issues and extended outages, the average load factor of the Belgian fleet plunged to 48.6 percent in 2018, the second lowest in the world behind Argentina. In 2019, it was back up to 79.1 percent.

The average age of the Belgian fleet exceeds 40 years for the first time (40.3 years).

The nuclear capacity constraints in the winters 2018–2019 and 2019–2020 were seen as test cases, as legally the country remains bound to a nuclear phase-out target of 2025. In January 2003, legislation was passed that requires the closure of all of Belgium's nuclear plants after 40 years of operation, so based on their startup dates, plants would be closed progressively between 2015 and 2025 (see Table 20). 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 a challenging policy goal.

In November 2017, the Belgian transmission system operator Elia published a study urging the construction of "at least 3.6 GW of new-build adjustable (thermal) capacity" to "cope with the shock of the nuclear exit in 2025"[1324]. The Belgian government confirmed the nuclear phase-out date, when, on 30 March 2018, it presented the Federal Energy Strategy.

Table 20 · Status of Belgian Nuclear Fleet (as of 1 July 2020)

Reactor	Net Capacity (MW)	Grid Connection	Operating Age (as of 1 July 2020)	End of License (Latest Closure Date)	Load Factor	
					2019	Lifetime
Doel-1	433	28/08/1974	45.8	10-year lifetime extension to 15 February 2025	57.6	80.4
Doel-2	433	21/08/1975	44.9	10-year lifetime extension to 1 December 2025	63.7	80.4
Doel-3	1 006	23/06/1982	38.0	1 October 2022	86.3	74.8
Doel-4	1 038	08/04/1985	35.2	1 July 2025	93.3	80.9
Tihange-1	962	07/03/1975	45.3	10-year lifetime extension to 1 October 2025	98.6	76.8
Tihange-2	1 008	13/10/1982	37.7	1 February 2023	36.8	76.5
Tihange-3	1 038	15/06/1985	35.0	1 September 2025	96.7	83.7

Sources: WNISR, NEI, 2020; Belgian Law of 28 June 2015; Electrabel/GDF-Suez, 2015[1325]

Shaky Legal Ground for 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—which later increased to over 13,000 and over 3,000—previously undetected defects. 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 or AFCN) authorized the restart of Doel-3 and Tihange-2 (see previous WNISR editions for details).

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

1324 - Elia, "Electricity Scenarios for Belgium Towards 2050–Elia's Quantified Study on the Energy Transition in 2030 and 2040", November 2017, see http://www.elia.be/~/media/files/Elia/About-Elia/Studies/20171114_ELIA_4584_AdequacyScenario.pdf, accessed 1 August 2019.

1325 - *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.

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. On 29 November 2018, the ECJ's Advocate General presented its advice on the request of the Belgian Constitutional Court concerning the applicability of the EU-Aarhus/Espoo with regards to the Plant Life Extension or PLEX of Doel-1 and -2 and Tihange-1. In her advice, the Advocate General clearly states that

> the definition of 'project' under Article 1(2)(a) of Directive 2011/92 [Environmental Impact Assessment Directive] includes the extension by 10 years of the period of industrial production of electricity by a nuclear power station

and that

> public participation must take place in accordance with Article 6(4) of Directive 2011/92 as early as possible, when all options are open, that is to say, before the decision on the extension is taken.[1326]

The ECJ is not bound by, but often follows, the advice of the Advocate General. In WNISR2019, we wrote: "Should the ECJ rule in accordance with the Advocate General's recommendations, this could have major implications also for past or planned lifetime extensions in other countries."

On 29 July 2019, the ECJ followed the Advocate General stating 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 [Environmental Impact Assessment] directive.[1327]

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.[1328]

1326 - InfoCuria, "Opinion of Advocate General Kokott", Case C-411/17, Inter-Environnement Wallonie ASBL, Bond Beter Leefmilieu Vlaanderen vzw v. Conseil des ministres, Intervener: Electrabel SA, Request for a preliminary ruling from the Constitutional Court of Belgium, Provisional text, 29 November 2018, see http://curia.europa.eu/juris/document/document.jsf?docid=208286&text=&dir=&doclang=EN&part=1&occ=first&mode=DOC&pageIndex=0&cid=7984750, accessed 27 June 2019.

1327 - 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", Press Release, 29 July 2020.

1328 - Ibidem.

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.[1329]

This precedent will have significant consequences on the 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.

In the meantime, Electrabel has signaled that it wished to extend 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.[1330]

Flaws in Reinforced Concrete and Other Issues

In October 2017, Electrabel identified serious flaws in the concrete of a building adjacent to the reactor buildings of Doel-3. These bunkered buildings contain backup systems for the safety of the facilities and are supposed to be able to withstand impact from outside like an airplane crash. According to Engie, some of these "anomalies at the reinforcements of the reinforced concrete [were] present since the construction of the building".[1331] Doel-3 was originally expected to be off-line for scheduled maintenance for 45 days, however, the outage lasted 302 days.

Similar problems, to varying degrees, have been identified at Tihange-2 and -3, as well as Doel-4.

The entire roof of the bunkered building of Tihange-3 is scheduled to be replaced during the outage that began on 7 June 2020 and is scheduled to last until 24 October 2020.

On 28 May 2020, Electrabel announced that the Tihange-1 will remain offline until the end of 2020, "following the discovery of a failure in a cooling water reservoir tank during an attempted restart of the unit after five months of planned maintenance".[1332]

The Federal Agency for Nuclear Control (FANC) noted in its March 2019 national progress report on the stress tests of nuclear power plants that review and assessment "progresses slightly slower than expected". The reasons indicated are workload related, for both licensee and regulator, triggered by the "safety events that occurred in 2018" and "by other safety projects (Long Term Operation of Tihange-1 or Doel-1 & -2) that are resource-~intensive for both organizations."[1333] While FANC had issued its annual progress reports in the month of March over the past few years, as of the end of July, the 2020 report had not been released yet.

1329 - Cour constitutionnelle, "La Cour annule la loi qui prolonge l'activité des centrales nucléaires de Doel 1 et 2, en l'absence d'études préalables d'incidences environnementales, mais en maintient les effets jusqu'au plus tard le 31 décembre 2022" ; Press Release, 5 March 2020 ; for the text of the judgement see Cour constitutionnelle, "Arrêt 34/2020", 5 March 2020, see https://www.const-court.be/public/f/2020/2020-034f.pdf, accessed 8 August 2020.

1330 - *Montel*, "Electrabel réitère son appel à prolonger le nucléaire belge", 28 January 2020, see http://www.montelnews.com/fr/story/electrabel-ritre-son-appel-à-prolonger-le-nuclaire-belge/1082410, accessed 8 August 2020.

1331 - Engie/Electrabel, "Révision en cours dans les centrales de Doel 3 et Tihange 3: réaction d'ENGIE Electrabel à propos de l'article dans *Le Soir*", 5 July 2018.

1332 - *Platts Nuclear News Flash*, "Vapor release in turbine hall takes Belgium's Tihange-2 offline", 15 July 2020.

1333 - FANC, "Belgian Stress Tests—National progress report on the stress tests of nuclear power plants", March 2019.

The COVID-19 pandemic has led Electrabel to revise by up to 25 weeks its outage schedules until 2023 for at least three of its seven reactors.[1334]

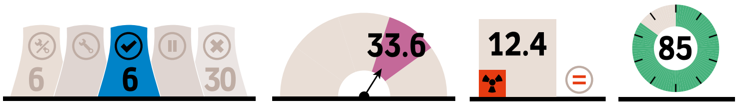
Finland

See Finland Focus.

France

See France Focus.

Germany



Germany's nuclear fleet generated 75.1 TWh gross[1335] (71.2 TWh net) in 2019, practically stable over the past three years, but less than half of the generation of 162.4 TWh (net) in the record year of 2001. Nuclear plants provided a stable 12.4 percent of Germany's electricity generation, representing little more than one-third of the historic maximum of 30.8 percent in 1997. One more reactor, the 1400-MWe Philippsburg-2 PWR, was closed at the end of 2019, according to the nuclear phase-out legislation that will see all six remaining reactors closed by the end of 2022 (see Table 21 for details). The average load factor slightly declined by 1.3 percentage points to 85.4 percent. All seven units that generated power in 2019 are in the Top Ten lifetime electricity generators in the world, five of which are holding positions one to five (only three U.S. reactors made it into the Top Ten alongside the German units).[1336]

Germany decided immediately after 3/11 to close eight of the oldest[1337] of its 17 operating reactors and to phase out the remaining nine until the end of 2022, effectively reactivating the "consensus agreement" negotiated between the Red-Green Government and the utilities in 2000–01 and the Nuclear Phase-out Law of January 2002. 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, which makes it virtually irreversible under any political constellation. On 6 June 2011, the 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).

Renewables generated 244 TWh (+8.7 percent) representing 40 percent of gross national electricity *generation* or 42 percent of gross national power *consumption* in 2019; more than half of this is from wind power (126 TWh), which, since 2017, out-generates nuclear power.

1334 - *Montel*, "Engie revises 2021-23 outage dates at 4 Belgian reactors", 21 July 2020.

1335 - AGEB, "Energieverbrauch in Deutschland im Jahr 2019", March 2020. Germany has not reported its 2019 net nuclear power production to IAEA-PRIS.

1336 - *NEI*, "Load factors to end December 2019", June 2020.

1337 - Including the Krümmel and Brunsbüttel reactors that by then had not generated power for almost two and four years respectively.

In the first half of 2020, based on preliminary estimates, renewables accounted for around half of the national electricity production (49 percent gross, according to Agora Energiewende[1338], and 55.8 percent net, according to the Fraunhofer-Institute for Solar Energy Systems[1339]) and consumption (50.3 percent, says Agora Energiewende). At the same time, national production shrank by 4.9 percent and the coal-based power generation declined by around 40 percent compared to the first half of 2019. Agora Energiewende warns that about two thirds of the decline is due to the COVID-19 effect, and that consumption and greenhouse gas emissions could rapidly rebound if there is no policy change, reinforcing efficiency, expansion of solar, and especially on-land wind power.

"Renewables covered 17.1% of final energy in Germany, nuclear 17.5% in France"

To put this into perspective, provisional figures for 2019 show respective shares of 17.1 percent for German renewables[1340] and 17.5 percent for French nuclear of final energy consumption.[1341] As renewables accelerate their expansion beyond the power sector throughout the German economy, their share in final energy has increased by more than 5 percentage points since 2010, while the French nuclear share remained about stable (16.9 percent in 2010). However, both figures indicate how modest the contribution of the respective technologies to the overall energy sector remains, with oil remaining the dominant primary source in both countries.

Coal-based electricity generation in Germany dropped by unprecedented margins in 2019—hard coal by 30.6 percent and lignite by 21.8 percent, while natural gas generation increased by 10.3 percent. Renewables were again by far the largest contributor to the power mix (gross) and supplied far more than lignite (18.6 percent) and hard coal (9.4 percent) together, while natural gas combustion for power was at an all-time high and contributed 14.9 percent. Electricity consumption dropped to its lowest level since 2000.[1342]

In 2019, net power exports plunged by one third to about 35 TWh. The main reasons were low gas prices that triggered higher production in neighboring countries and the cost increase of emission certificates, which drove up the cost of German coal-based electricity. The parallel decline of coal/lignite power generation and exports clearly indicate that a significant share of exports is coal-based (e.g. to France that struggles with winter peaks).

Figure 66 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 2019.

1338 - Agora Energiewende, "Stromerzeugung im ersten Halbjahr 2020", 30 June 2020, see https://www.agora-energiewende.de/blog/default-5ec368c8fd/, accessed 9 August 2020.

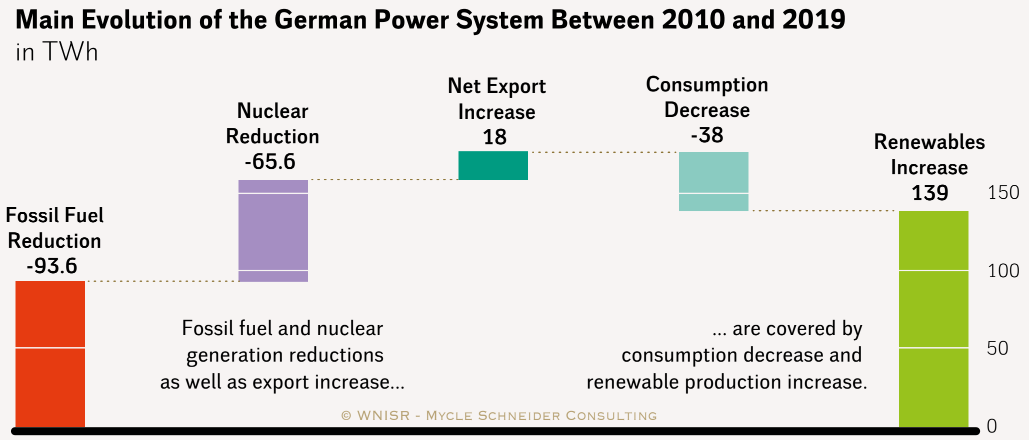
1339 - ISE, Fraunhofer Institut, "Nettostromerzeugung im 1. Halbjahr 2020: Rekordanteil erneuerbarer Energien von 55,8 Prozent", 1 July 2020, see https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2020/nettostromerzeugung-im-ersten-halbjahr-2020-rekordanteil-erneuerbarer-energien.html, accessed 9 August 2020.

1340 - Share calculated according to EU-Directive 2009/28/EC. The share calculated according to German Energiekonzept is 17.5 percent, see Federal Ministry for Economic Affairs and Energy, "Development of Renewable Energy Sources in Germany in the year 2019", February 2020.

1341 - General Commission for Sustainable Development, "Bilan énergétique de la France en 2018–Données provisoires", French Ministry for the Ecological and Inclusive Transition, April 2019.

1342 - AGEB, "Energieverbrauch in Deutschland im Jahr 2019", op.cit.

Figure 66 · Main Developments of the German Power System Between 2010 and 2019



Sources: WNISR based on AGEB, 2020

It illustrates that Germany has definitely now embarked on the double phase-out of nuclear power *and* coal. Renewable electricity generation (+139 TWh) and the reduction in domestic consumption (–38 TWh) were more than sufficient to compensate for the reduction of nuclear generation (–65.6 TWh), and a dramatic reduction in power generation from fossil fuels (–93.6 TWh). Within the fossil-fuel generating segment:

- Lignite peaked in 2013 and then declined—especially in 2019— to 22 percent below the 2010 level;
- Hard coal also peaked in 2013 then dropped to less than half (49 percent) of the 2010 level;
- Natural gas fluctuated since 2010 and peaked in 2019 at 2 percent above the 2010 level;
- Oil was insignificant and dropped further to 41 percent below the 2010 level representing 0.8 percent of the gross power generation.

Greenhouse gas emissions from the power sector dropped by an estimated 18 percent or 50 million tons of CO_2 in 2019, mainly due to higher carbon prices in the EU emissions trade and therefore lower coal and lignite use, lower electricity consumption and higher renewable energy contribution.

Carbon intensity of the power mix decreased by 12.6 percent from 474 to 414 g CO_2/kWh.[1343]

1343 Agora Energiewende, "Die Energiewende im Stromsektor: Stand der Dinge 2019—Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2020", January 2020 (in German), see https://www.agora-energiewende.de/veroeffentlichungen/die-energiewende-im-stromsektor-stand-der-dinge-2019/, accessed 9 August 2020.

Table 21 · 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)	RWE	1974	6 August 2011
Biblis-B (PWR, 1240 MW)	RWE	1976	
Brunsbüttel (BWR, 771 MW)	KKW Brunsbüttel[a]	1976	
Isar-1 (BWR, 878 MW)	PreussenElektra	1977	
Krümmel (BWR, 1346 MW)	KKW Krümmel[b]	1983	
Neckarwestheim-1 (PWR, 785 MW)	EnBW	1976	
Philippsburg-1 (BWR, 890 MW)	EnBW	1979	
Unterweser (BWR, 1345 MW)	PreussenElektra	1978	
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)	PreussenElektra/Vattenfall[d]	1986	31 December 2021
Grohnde (PWR, 1360 MW)	PreussenElektra	1984	
Gundremmingen-C (BWR, 1288 MW)	KKW Gundremmingen	1984	
Isar-2 (PWR, 1410 MW)	PreussenElektra	1988	31 December 2022
Emsland (PWR, 1329 MW)	KKW Lippe-Ems[e]	1988	
Neckarwestheim-2 (PWR, 1310 MW)	EnBW	1989	

Sources: Atomgesetz, 31 July 2011, Atomforum Kernenergie May 2011; WNISR with IAEA-PRIS, 2020

Notes:

Krümmel and Brunsbüttel were officially closed in 2011 but had not been providing electricity to the grid since 2009 and 2007 respectively

a - Vattenfall 66.67%, E.ON 33.33%

b - Vattenfall 50%, E.ON 50%.

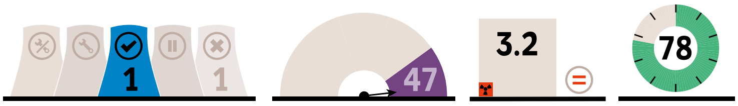
c - RWE 75%, E.ON 25%.

d - E.ON 80%, Vattenfall 20%.

e - RWE 87.5%, E.ON 12.5%.

PWR: Pressurized Water Reactor; BWR: Boiling Water Reactor; KKW: Nuclear Power Plants (Kerkraftwerk);
RWE: Rheinisch-Westfälisches Elektrizitätswerk Power AG; EnBW: Energie Baden-Württemberg AG.

The Netherlands



The Netherlands operates a single, 47-year-old 480 MW PWR at Borssele that provided a stable 3.7 TWh and 3.15 percent of the country's electricity in 2019, compared with a maximum of 6.2 percent in 1986. In late 2006, the operator and the Government reached an agreement to allow operation of the reactor to continue until 2033.[1344] In June 2020, operator EPZ (Elektriciteits Produktiemaatschappij Zuid-Nederland) announced a return to profit of around €20 million (US$22.6 million) for 2019,[1345] compared to losses of €50 million (US$56 million) for 2018.[1346]

1344 - WNA, "Nuclear Power in the Netherlands", Updated February 2017,
see http://www.world-nuclear.org/info/inf107.html, accessed 17 June 2019.

1345 - Rolf Bosboom, "Energy company PZEM is out of the red, but 2020 will be 'a difficult year'", *PZC*, 4 June 2020 (in Dutch),
see https://www.pzc.nl/zeeuws-nieuws/energiebedrijf-pzem-is-uit-de-rode-cijfers-maar-2020-wordt-een-moeilijk-jaar~a61684a7/, accessed 10 June 2020.

1346 - Frank Balkenende, "PZEM's birthday is full of confidence again", *PZC*, 2 May 2019 (in Dutch),
see https://www.pzc.nl/zeeuws-nieuws/jarig-pzem-blaakt-weer-van-het-zelfvertrouwen~a8cd3352/, accessed 10 June 2020.

The ruling governing party VVD announced in January 2019 that it was developing new ideas for nuclear power in Netherlands. The options under consideration were further extension of operations at Borssele, construction of a new plant, or realizing new nuclear power plants in a European context. The response from industry in the Netherlands was to dismiss the initiative as wholly unrealistic. "The business case for nuclear energy is all in all very unattractive," said energy company Eneco, as "the cost of nuclear energy is currently two to three times higher than renewable energy from wind and solar."[1347] The operator of Borssele in May 2019 stated that any new nuclear plant would "never happen" without government financing.[1348]

In March 2020, the province of Zeeland, which is a part owner of the Borssele plant, indicated its support for continued operation of the reactor beyond 2033—that is beyond 60 years—as part of its strategy to meet its climate goals.[1349] In its Regional Energy Strategy, Zeeland called on the reactor operator, Elektriciteits Produktiemaatschappij Zuid-Nederland (EPZ), to provide details as to what it would be required for the reactor to operate for more than another dozen years. It was reported that EPZ is interested in possible life extension.[1350] German utility Rheinisch-Westfälisches Elektrizitätswerk AG (RWE), that holds 30 percent of Borssele, has not indicated its position. The current Dutch Nuclear Energy Act does not permit life extension and would have to be amended.

In 2019, it was reported that Netherlands is lagging behind much of the rest of Europe when it comes to reaching sustainable energy targets, according to figures from the European statistics agency, Eurostat.[1351] In 2018, just 7.4 percent of the energy used in the Netherlands came from renewable energy, with a target of 14 percent by 2020.[1352] The Dutch environmental assessment agency stated that the Netherlands will not meet its target of cutting carbon dioxide emissions by 25 percent by 2020 when compared with 1990.[1353]

In October 2018, the Dutch government was found to be in non-compliance with the Aarhus Convention when it failed to conduct a public consultation on extending the operating life of Borssele.[1354] The convention is an international environmental agreement under the auspices of the UN Economic Commission for Europe (UNECE) which addresses access to information and public participation. The ruling requires the Dutch government to conduct an Environmental

1347 - David Bremmer, "Energy giants fill the VVD proposal for new nuclear power stations", *AD*, 6 November 2018 (in Dutch), see https://www.ad.nl/economie/energiereuzen-fileren-vvd-voorstel-voor-nieuwe-kerncentrales~a93c015e/, accessed 12 June 2019.

1348 - Frank Balkenende, "PZEM's birthday is full of confidence again", *PZC*, 2 May 2019, op. cit.; and Laka, "PZEM: "profit again in 2021; no new nuclear power plant without a subsidy", 3 May 2019 (in Dutch), see https://www.laka.org/nieuws/2019/pzem-in-2021-weer-winst-geen-nieuwe-kerncentrale-zonder-subsidie-10626, accessed 12 June 2019.

1349 - *NOS*, "Nuclear power plant Borssele may remain open longer", 10 March 2020 (in Dutch), see https://nos.nl/artikel/2326559-kerncentrale-borssele-blijft-mogelijk-langer-open.html, accessed 10 June 2020.

1350 - Frank Balkenende, "Keep nuclear power plant Borssele open longer? It is now up to the state", *PZC*, 19 March 2020 (in Dutch), see https://www.pzc.nl/zeeuws-nieuws/kerncentrale-borssele-langer-openhouden-rijk-is-nu-aan-zet-a0c121f75/, accessed 10 June 2020.

1351 - *Dutch News.nl*, "The Netherlands still trailing behind on EU renewable energy targets", 12 February 2019, see https://www.dutchnews.nl/news/2019/02/the-netherlands-still-trailing-behind-on-eu-renewable-energy-targets/, accessed 10 June 2020.

1352 - Eurostat, "Renewable energy statistics", see https://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics#Renewable_energy_produced_in_the_EU_increased_by_two_thirds_in_2007-2017, accessed 10 June 2020.

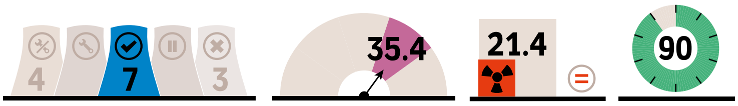
1353 - Mike Corder, "Dutch emission reduction targets probably won't be met", *Associated Press*, 1 November 2019, see https://phys.org/news/2019-11-dutch-emission-reduction-wont-met.html, accessed 28 July 2020.

1354 - UNECE, "Findings and recommendations with regard to communication ACCC/C/2014/104 concerning compliance by the Netherlands", Adopted by the Compliance Committee on 4 October 2018, Economic Commission for Europe, Meeting of the Parties to the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, Compliance Committee, 63rd meeting, 11–15 March 2019, see https://www.unece.org/fileadmin/DAM/env/pp/compliance/CC-63/ece.mp.pp.c.1.2019.3.en.pdf, accessed 12 June 2019.

Impact Assessment (EIA) involving stakeholders in the Netherlands, but also in neighboring states. The evidence of non-compliance was submitted to Aarhus by Greenpeace Netherlands, which had lost previous claims in Dutch courts on the public consultation process.

In 2014, EPZ started using uranium-plutonium Mixed Oxide (MOX) fuel at Borssele. EPZ is currently the only remaining foreign customer for commercial spent fuel reprocessing of Orano's La Hague plant. The plan is to consume all of the plutonium that is separated in as much as 40 percent MOX in the core, likely a higher share than any other commercial light water reactor in the world operating with MOX fuel, and definitely the oldest.[1355]

Spain



Spain operates seven reactors that provided 55.9 TWh in 2019, a slight increase compared to the 53.4 TWh in 2018, representing 21.5 percent of the country's electricity, compared to 20.4 percent in 2018 and a maximum of 38.4 percent in 1989. Spain's reactors have a mean operating age of 35.4 years as of 1 July 2020. Meanwhile, in the year to May 2020, solar PV installed capacity doubled from 4.62 GW to 9.28 GW,[1356] generating 98 TWh total electricity in 2019, representing 37.5 percent of the nation's electricity.[1357]

The end of the conservative government of Mariano Rajoy and the formation of a new government in May 2018 under Socialist Party (PSOE) leader Pedro Sánchez led to a major shift in energy and climate policy.[1358] The PSOE policy platform in 2016 had focused on energy efficiency and renewable energy, while reducing fossil fuel use and a commitment to permit operation of Spain's reactors for a maximum of forty years.[1359] Shortly after forming a coalition government, it restated that a nuclear phase-out would take place between 2021–2028.[1360]

In late January 2019, a new nuclear phase-out plan was agreed between the then PSOE-led government and utilities Endesa, Iberdrola and Naturgy. The phase-out was part of the overall Integrated National Energy and Climate Plan (INECP) which was approved by the Cabinet meeting on 22 February 2019.[1361] The details of the reactor closure-dates were published in February 2019 by newspaper *Cinco Días*.[1362] All of Spain's reactors would be closed by 2035; however, the policy also secures lifetime extension of all reactors beyond 40 years, in contrast

1355 - Jan Wieman, "Borssele moves to MOX", Fuel Cycle Manager – EPZ, as published in *NEI*, 11 March 2015, see http://www.neimagazine.com/features/featureborssele-moves-to-mox-4530062/, accessed 14 June 2019.

1356 - *Argus*, "Spanish solar PV capacity doubles in a year to top coal", 11 June 2020, see https://www.argusmedia.com/en/news/2113565-spanish-solar-pv-capacity-doubles-in-a-year-to-top-coal, accessed 16 June 2020.

1357 - *Renewables Now*, "Spain connects close to 6.5 GW of renewables in 2019", 24 January 2020, see https://renewablesnow.com/news/spain-connects-close-to-65-gw-of-renewables-in-2019-684733/, accessed 28 July 2020.

1358 - Manuel Planelles, "Spain's new PM signals change of tack on climate change", *El País*, 6 June 2018, see https://elpais.com/elpais/2018/06/06/inenglish/1528270804_597351.html, accessed 16 June 2020.

1359 - PSOE, "Programa Electoral—Elecciones Generales 2016", 2016 (in Spanish), see https://www.psoe.es/transparencia/informacion-politica-organizativa/programa/.

1360 - Sam Morgan, "Spain to nix nuclear and coal power by 2030", *Euractiv*, 15 November 2018, see https://www.euractiv.com/section/energy/news/spain-to-nix-nuclear-and-coal-power-by-2030/, accessed 28 July 2020.

1361 - Carmen Monforte, "El Gobierno cierra el calendario con las fechas de clausura de cada central nuclear", *CincoDías*, *El País Economía*, 11 February 2019 (in Spanish), see https://cincodias.elpais.com/cincodias/2019/02/08/companias/1549647160_807281.html, accessed 16 June 2020.

1362 - Ibidem.

to previous stated PSOE policy. On 3 March 2019, Teresa Ribera, Minister for the Ecological Transition, confirmed that an agreement had been reached with Iberdrola, Endesa and Naturgy that in effect extends operation of their reactors.[1363] After inconclusive elections in April and November 2019, with a narrow victory for PSOE, a coalition agreement for government was reached with left-of-center Podemos.[1364]

In March 2020, the government updated the INECP 2021-2030.[1365] The 2030 target of 161 GW of total installed power generating capacity is to include 50 GW of wind, 39 GW PV, 27 GW CCGTs (Combined Cycle Gas Turbines), 16 GW hydro, 9.5 GW pumped hydro, 7 GW thermo-solar, 3 GW nuclear (1.9 percent).[1366]

A major point of tension between the utilities was over the amortization time of their reactors. Iberdrola had accounted for the nuclear plants' operating until 40 years, whereas Endesa had planned for 50-year operation in its accounts. Iberdrola said that it also has no financial incentive to continue nuclear operations if the business continues to lose money.[1367] Iberdrola and Naturgy had put forward plans for extension of the Almaraz reactors to 2027, of which they jointly share ownership together with Endesa, on the condition that they would be able to withdraw if there was a requirement to make further investments. Endesa, which was not in favor of reactor closure before 50 years, set no conditions. On 22 March 2019, Iberdrola confirmed that it had reached agreement for the extension of the Almaraz-1 and -2 reactors to operate until 1 November 2027 and 31 October 2028 respectively, and that it had applied for license extension.[1368] The agreement is based on the condition that Iberdrola will spend no more than €600 million (US$677 million) during the remaining operational life of the reactors.[1369]

On 7 May 2020, the Plenary of the Nuclear Safety Council (CSN) announced that it had decided to approve a technical assessment on the request for license renewal for the two Almaraz reactors.[1370] As a result, CSN recommends to the Government to authorize the 39-year old Almaraz-1 to operate until 1 November 2027 and Almaraz-2, connected to the grid in October 1983, to operate until 31 October 2028. The approval by CSN set safety and compliance conditions, including the requirement, as noted above, to invest up to €600 million

1363 - *Público*, "La ministra Ribera afirma que es necesario prolongar la vida de las centrales nucleares", 3 March 2019 (in Spanish), see https://www.publico.es/politica/energia-nuclear-prolonga-vida-centrales-nucleares.html, accessed 16 June 2020.

1364 - *El País*, "Socialists and Unidas Podemos strike preliminary deal to form coalition government", 13 November 2019, see https://english.elpais.com/elpais/2019/11/12/inenglish/1573562718_041862.html, accessed 16 June 2020.

1365 - *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 28 July 2020.

1366 - Massimo Schiavo, Pierre Georges et al., "The Energy Transition And What It Means For European Power Prices And Producers: Midyear 2020 Update", *S&P Global*, 8 June 2020, see https://www.spglobal.com/ratings/en/research/articles/200608-the-energy-transition-and-what-it-means-for-european-power-prices-and-producers-midyear-2020-update-11509932, accessed 28 July 2020.

1367 - *NW*, "Spain's Endesa to apply to renew all reactor licenses in 2019, 2020", *Platts*, 7 March 2019.

1368 - 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 16 June 2020.

1369 - 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 16 June 2020.

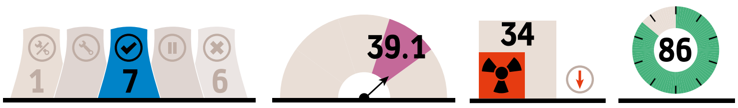
1370 - CSN, "El CSN informa favorablemente la renovación de la autorización de explotación de la central nuclear Almaraz (Cáceres)", 7 May 2020 (in Spanish), see https://www.csn.es/noticias-csn/2020/-/asset_publisher/7wHne5sV6dgf/content/el-csn-informa-favorablemente-la-renovacion-de-la-autorizacion-de-explotacion-de-la-central-nuclear-almaraz-caceres-, accessed 16 June 2020.

(US$677 million).[1371] In June 2020, a decision on whether to grant extension of the licenses for the Almaraz reactors was postponed by the Government until late August 2020.[1372]

The Almaraz plant is located adjacent to the Tagus River in an area of significant seismic risk and 110 kilometers from the Portuguese border.[1373] For this reason the continued operation of the plant has been opposed by Portuguese environmental groups, political parties and governments. The decision of the CSN prompted the Portuguese government to demand that Almaraz be subject to an environmental impact assessment.[1374]

Asociación Nuclear Ascó-Vandellós II, known as ANAV, the operator of Vandellos-2, has applied for 10-year license renewal taking it to 2030.[1375] Under the recently agreed Integrated Energy and Climate Plan, Vandellos-2 is scheduled to operate until 2034, and therefore a further license extension may be sought prior to 2030. On 24 June 2020, the CSN approved a ten-year extension for Vandellos-2 until 2030.[1376] The reactor is scheduled for closure in 2034.[1377]

Sweden



Sweden's nuclear fleet of eight reactors generated 64.4 TWh or 34 percent of the country's electricity production in 2019, a drop of 2.2 percent in generation and 6.3 percentage points if compared to 65.9 TWh and 40.3 percent in 2018. On 30 December 2019, the 45-year old Ringhals-2 reactor was permanently closed,[1378] leaving the country with seven operating reactors. State-owned utility Vattenfall co-owns six operating reactors,[1379] while OKG (Oskarshamns Kraftgrupp AB)[1380] owns the seventh, Oskarshamn-3.

The past year has seen a continuation of efforts by right-of-center opposition parties to overturn the decision in 2016 on shutting down all nuclear reactors in Sweden by 2040. On 10 December 2019, the Moderate Party and the Christian Democrats announced their

1371 - *Eleconomista*, "El CSN autoriza a la central nuclear de Almaraz a operar hasta octubre de 2028", 7 May 2020 (in Spanish), see https://www.eleconomista.es/empresas-finanzas/noticias/10529185/05/20/El-CSN-autoriza-a-la-central-nuclear-de-Almaraz-a-operar-hasta-octubre-de-2028.html, accessed 16 June 2020.

1372 - *El Periódico*, "La decisión sobre Almaraz, aplazada", 6 June 2020 (in Spanish), see https://www.elperiodicoextremadura.com/noticias/extremadura/decision-almaraz-aplazada_1236171.html, accessed 28 July 2020.

1373 - *Jornal Económico*, "Spanish nuclear power plant in Almaraz authorized to operate until 2028", 8 May 2020, see https://jornaleconomico.sapo.pt/en/news/Spanish-nuclear-power-plant-in-Almaraz-authorized-to-operate-until-2028-586165, accessed 16 June 2020.

1374 - *Notícias ao Minuto*, "Governo quer que extensão de funcionamento de Almaraz seja avaliada", 5 May 2020 (in Portuguese), see https://www.noticiasaominuto.com/pais/1483078/governo-quer-que-extensao-de-funcionamento-de-almaraz-seja-avaliada, accessed 16 June 2020.

1375 - *Platts Nuclear News Flashes*, "Operator of Spain's Vandellos-2 applies for 10-year license renewal", 28 March 2019.

1376 - CSN, "El Pleno del CSN informa favorablemente la solicitud de renovación de autorización de explotación de la central nuclear Vandellós II (Tarragona)", 24 June 2020 (in Spanish), see https://www.csn.es/noticias-csn/2020/-/asset_publisher/7wHne5sV6dgf/content/el-pleno-del-csn-informa-favorablemente-la-solicitud-de-renovacion-de-autorizacion-de-explotacion-de-la-central-nuclear-vandellos-ii-tarragon-1, accessed 28 July 2020.

1377 - *Platts Nuclear News Flashes*, "Spain approves 10-year license extension for Vandellos-2 reactor", 25 June 2020.

1378 - Vattenfall, "Ringhals 2 nuclear plant shuts down", 19 December 2019, see https://group.vattenfall.com/press-and-media/news--press-releases/newsroom/2019/ringhals-2-nuclear-plant-shuts-down; and *Svenska Dagbladet*, "Ringhals 2 tystnade: 'Vemod'", 30 December 2019 (in Swedish), see https://www.svd.se/medelalders-elforsorjare-tystnar, both accessed 16 June 2020.

1379 - Ringhals-1–4 (Vattenfall 70.4%, E.ON 29.6%), Forsmark-1–3 (Forsmarks Kraftgrupp FKG, Vattenfall 66%, Mellansvensk Kraftgrupp 25.5%, E.ON 8.5%)

1380 - OKG is owned by Uniper Sverige (formerly Sydkraft), an E.ON spinoff, for 54.5% and Fortum for 45.5%.

withdrawal from the June 2016 energy policy agreement.[1381] This was when the ruling Red Green coalition and three opposition parties, including the Center Party, had reached a "traditional Swedish compromise" on future energy policy,[1382] which fixed a 2040 target for a 100-percent renewable electricity mix.

Even after the closure of Ringhals-2 in December 2019, calls have continued to reverse the decision and scrap plans for closure of Ringhals-1, which is scheduled no later than 31 December 2020. A parliamentary motion on 22 January 2020 attempting to reverse the closure of the Ringhals reactors failed by one vote. The motion was put forward by the far-right Sweden Democrats party, and backed by the Moderates, the Liberals and the Christian Democrats, and was opposed by the Social Democratic Party and Green Party coalition-government. However, a conservative parties' victory would not necessarily have led to re-operation of Ringhals-2 or prevented the closure of Ringhals-1 later this year.

As reported in WNISR2019, the efforts to stop the closure of Ringhals conflicts with the position of the reactor owners. Vattenfall's decision to close the reactors was due to the reactors being uneconomic, safety concerns over containment aging, the requirement for major investment in many upgrades, as well as the need for new licensing.[1383] On 28 November 2019, the head of the company's generation department, Torbjorn Wahlborg, said that Vattenfall never intended to operate Ringhals-1 and -2 longer than into the mid-2020s. He added that although electricity prices are higher now (at the end of 2019) than they were in 2015 when the company took the decision to close the reactors, "there is so much renewable energy in the [electricity] system that there is no place in the market for these reactors."[1384]

For more than four decades phasing out nuclear power has been on the agenda in Sweden. A 1980 public referendum decided to end 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 phase-out earlier but abandon the 2010 deadline. The first reactor (Barsebäck-1) was closed in 1999 and the second one (Barsebäck-2) in 2005. In June 2010, the parliament voted by a tight margin (174–172) to abandon the phase-out legislation. As a result, theoretically, a new plant could again be built—but only if an existing plant is closed.

On 22 December 2016, the 40-year-old Oskarshamn-2 was officially closed, followed on 17 June 2017 with the closure of the 46-year-old Oskarshamn-1.[1385]

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

1381 - *Svenska Dagbladet*, "M och KD lämnar – vill ha svar om kärnkraften", 10 December 2019 (in Swedish), see https://www.svd.se/m-och-kd-ratar-energioverenskommelsen, accessed 16 June 2020.

1382 - Government Offices of Sweden, "Agreement on Swedish energy policy—Framework agreement between the Swedish Social Democratic Party, the Moderate Party, the Swedish Green Party, the Centre Party and the Christian Democrats", 16 June 2016, see https://www.government.se/articles/2016/06/agreement-on-swedish-energy-policy/, accessed 1 August 2020.

1383 - Birgitta Forsberg, "Vattenfalls vd: Mer kärnkraft inte lösningen", *Svenska Dagbladet*, 20 May 2019 (in Swedish), see https://www.svd.se/vattenfalls-vd-mer-karnkraft-inte-losningen, accessed 24 June 2019; and Lars Larsson, "Kärnkraftsförespråkare förlorade om Ringhals", *Svenska Dagbladet*, 22 January 2020 (in Swedish), see https://www.svd.se/riksdagen-rostar-om-ringhals, accessed 16 June 2020.

1384 - Ariane Sains, "Swedish parliament to debate continued operation of Ringhals reactors", *NW*, 2 January 2020.

1385 - WNISR, "Sweden Retires First Commercial Nuclear Reactor (Oskarshamn-1)", 21 June 2017, see https://www.worldnuclearreport.org/Sweden-Retires-First-Commercial-Nuclear-Reactor-Oskarshamn-1.html, accessed 24 June 2019.

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.[1386] The 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."[1387] This could mean significant repair work may be indispensable in the coming years.

The SSM on 19 May 2020, approved routine operation after a power increase of Forsmark-2.[1388] The uprating of Forsmark was to 1118 MWe net. The original design capacity was 900 MWe net.

Major construction work at all of Sweden's reactors is scheduled for completion during 2020. This relates to the requirement that all reactors operating beyond 2020 have in place Independent Core Cooling Systems (ICCS).[1389] The new system is a consequence of the stress tests following the Fukushima accident and the SSM requirements for an independent core cooling system, designed to withstand extreme external hazards.

The 2016 policy agreement also allowed for the building of new reactors, but, as in the previous agreement, only for replacement and not in addition to existing units. The agreement also stipulated: "Central Government support for nuclear energy, in the form of direct or indirect subsidies, cannot be assumed".[1390] While Vattenfall CEO Hall stated in May 2019 that "the disadvantage of nuclear power is that it has become so expensive to build that it is difficult to motivate to build new nuclear power,"[1391] the company has indicated during the past year that it is open to operating reactors beyond the 2040 deadline.[1392] "We will consider the possibility of driving them longer," said Torbjörn Wahlborg, production manager at Vattenfall.[1393]

Currently, six of the seven Swedish reactors are scheduled for 60-year operation into the 2040s, with closure of the last reactor in 2045,[1394] when Sweden plans to have 100 percent of its electricity generated by renewable energy.

1386 - SSM, "Forsmark har förutsättningar att fortsätta driva F1 och F2 strålsäkert till 2028s", 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.

1387 - SSM, "Återkommande helhetsbedömning / Forsmarks Kraftgrupp AB / Forsmark 1 och 2", 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.

1388 - SSM, "Rutinmässig drift efter effekthöjning av Forsmark 2 godkänd", 19 May 2020 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/press/nyheter/2020/rutinmassig-drift-efter-effekthojning-av-forsmark-2-godkand/, accessed 16 June 2020.

1389 - 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.

1390 - Government Offices of Sweden, "Framework agreement between the Swedish Social Democratic Party, the Moderate Party, the Swedish Green Party, the Centre Party and the Christian Democrats", 16 June 2016.

1391 - Birgitta Forsberg, "Vattenfalls vd: Mer kärnkraft inte lösningen", *Svenska Dagbladet*, 20 May 2019 (in Swedish), op. cit.

1392 - Lovisa Åkesson, "Vattenfall öppnar för kärnkraft efter 2040", *Expressen*, 24 November 2019 (in Swedish), see https://www.expressen.se/nyheter/klimat/vattenfall-oppnar-for-karnkraft-efter-2040-/, accessed 16 June 2020.

1393 - *svt Nyheter*, "Ringhals ägare öppnar för ny kärnkraft", 23 November 2019 (in Swedish), see https://www.svt.se/nyheter/inrikes/ringhals-agare-oppnar-for-nya-karnkraftverk, accessed 16 June 2020.

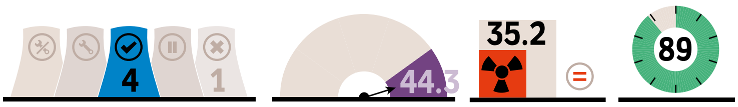
1394 - Vattenfall, "Asset Management At Nuclear Power Plants—With International Standards And Principles", IAEACN-246-14, Presented at the 4th International Conference on NPP Life Management", IAEA, 23–27 October 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-10-23-10-27- NPTDS/054_Frojd_ Presentation.pdf, accessed 24 June 2019.

New emergency planning zones and emergency planning distances were announced in June 2020 for Swedish nuclear power plants.[1395] The sites will be surrounded by a Precautionary Action Zone (PAZ) and an Urgent Protective action planning Zone (UPZ) as well as an Extended Planning Distance (EPD), extending approximately 5, 25 and 100 kilometers respectively. With SSM stating that

> An inner and an outer emergency planning zone extending approximately 5 and 25 kilometers respectively will be introduced around each of Sweden's nuclear power plants. Within these emergency planning zones, iodine tablets will be pre-distributed, warnings for the public in the event of a nuclear accident will be pre-planned, and plans for evacuation and sheltering will be put in place. (...) For the extended planning distance [out to 100 km], planning will be put in place for relocation based on input from measurements of ground deposition, sheltering, and limited distribution of iodine tablets. (...) The new emergency planning zones and distances are to be implemented in Swedish contingency planning no later than 1 July 2022.[1396]

The reorganization of emergency planning will likely have significant cost implications for nuclear operators.

Switzerland



Prior to the U.K. leaving the EU on 31 January 2020, Switzerland has been the only non-EU Western European country generating nuclear power. Swiss nuclear output was stable at 25.3 TWh in 2019 (less than 1 percentage-point increase over 2018). The average load factor was 89.1 percent, up from 88.3 percent in 2018. Nuclear generated a stable 35.2 percent of the country's electricity (36.1 percent in 2018, maximum of 44.4 percent in 1996).[1397] With an average age of 44.3 years (see Figure 67), Switzerland operates the oldest nuclear fleet and—with Beznau-1, age 51 since grid connection—the oldest commercially operating reactor in the world.

In October 2013, operator BKW announced that it would close its Mühleberg reactor in 2019, due to "indefinable and unquantifiable… technical, economic and political uncertainties [that] could increase the economic risks of long-term operation."[1398] In March 2016, BKW communicated that Mühleberg would be disconnected from the grid as of 20 December 2019.[1399] On 20 June 2018, the Federal Energy Department issued the formal closure decision and

1395 - SSM, "New emergency and planning zones are introduced around Swedish nuclear power plants", 18 June 2020, see https://www.stralsakerhetsmyndigheten.se/en/press/news/2020/new-emergency-and-planning-zones-are-introduced-around-swedish-nuclear-power-plants/, accessed 20 July 2020.

1396 - Ibidem.

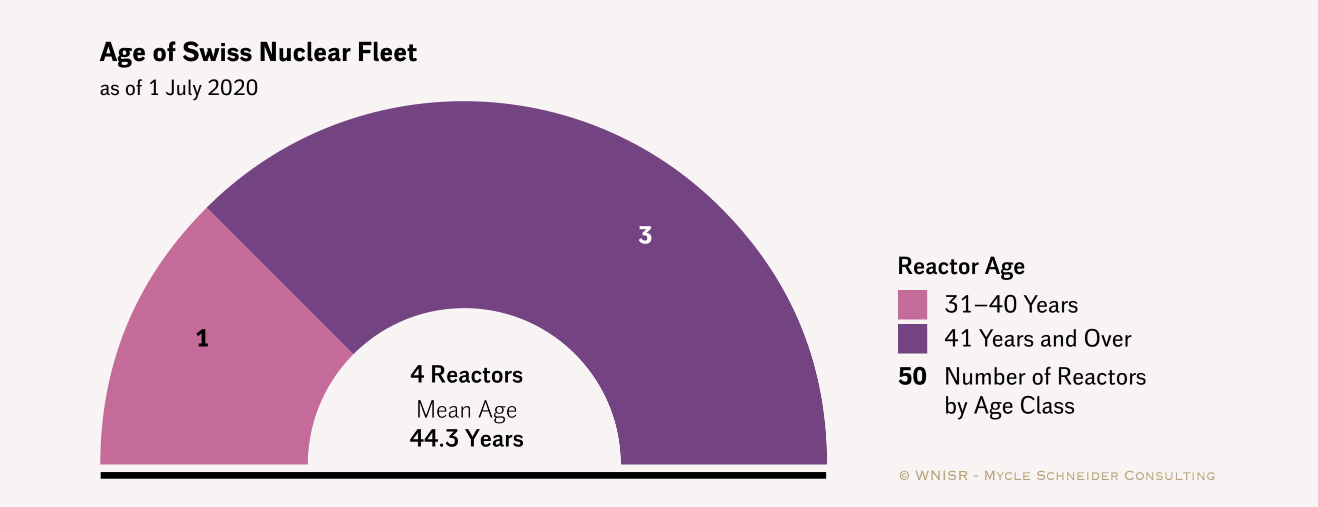
1397 - SFOE/BFE, "Schweizerische Elektrizitätsstatistik 2019/Statistique Suisse de l'Électricité 2019", Swiss Federal Office of Energy, June 2019 (in German and French), see https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/elektrizitaetsstatistik.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvMTAxMTI=.html, accessed 3 August 2020. The official national figures vary slightly from the IAEA-PRIS statistics.

1398 - *NIW*, "Switzerland—Briefs", 1 November 2013.

1399 - BKW, "Kernkraftwerk Mühleberg geht am 20. Dezember 2019 definitiv vom Netz—Endgültige Einstellung des Leistungsbetriebs", Press Release, 2 March 2016 (in German), see https://www.bkw.ch/en/about-us/newsroom/details/kernkraftwerk-muehleberg-geht-am-20-dezember-2019-definitiv-vom-netz, accessed 15 June 2016.

granted a general decommissioning license.[1400] The closure date of the Mühleberg nuclear unit was respected with Swiss precision and the reactor was disconnected from the grid on the target date.

Figure 67 · Age Distribution of the Swiss Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2020

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 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" was adopted by the Swiss parliament on 1 November 2017 and entered into force on 1 January 2018.[1401]

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 is to decrease by 3 percent by the end of 2020 and 13 percent by 2035. According to the "Energy Strategy 2050 Monitoring Report 2019", final energy consumption per capita (weather-adjusted) had decreased by 17.2 percent as of the end of 2018, while per-capita power consumption had decreased by 6.4 percent—as in the previous year, both indicators are already exceeding the 2020 targets.[1402] In addition, per-capita power consumption decreased by another 1.5 percent in 2019, so Switzerland has again demonstrated that significantly more ambitious targets would be achievable.

1400 - UVEK/DETEC, "Verfügung des Eidgenössischen Departements für Umwelt, Verkehr, Energie und Kommunikation UVEK vom 20. Juni 2018—betreffend Gesuch vom 18. Dezember 2015 auf Anordnung der Stilllegung für das Kernkraftwerk Mühleberg", Federal Department of the Environment, Transport, Energy and Communications, 20 June 2018, see https://www.bkw.ch/fileadmin/user_upload/17_Stilllegung/2015/2018.06.20_Stilllegungsverf%C3%BCgung_KKM_Internet.pdf, accessed 13 August 2020.

1401 - SFOE, "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.

1402 - SFOE, "Energy Strategy 2050—Monitoring Report 2019", Abridged Version, Swiss Federal Office of Energy, November 2019, see https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/monitoring-energy-strategy-2050.html, accessed 19 September 2020; and SFOE, "Stratégie Énergétique 2050—Rapport de Monitoring 2019/Energiestrategie 2050—Monitoring-Bericht 2019", November 2019 (in French and German).

Domestic production of non-hydro renewable-energy based electricity is to reach a modest target of 4.4 TWh by 2020, which was almost achieved in 2019 with 4.2 TWh and represents only 5.8 percent of the net power generated.[1403]

The demand to significantly increase the targets for renewables is therefore a logical point of public demand in the ongoing debate around a new energy bill. The government has decided to liberalize the electricity market and adapt the energy legislation accordingly. It has stated that a key goal of the reform would be to stimulate distributed renewable energies, including collective auto-consumer and energy-coop schemes.[1404]

An August-2019 study into the potential effects of a major nuclear accident in one of the then five operating Swiss and four French reactors at Bugey concluded:

> The average number of people to be resettled in Europe would range between 250,000 and 500,000 (from the least impacting nuclear power plant to the most impacting one). Such a situation could be unmanageable by governmental bodies.
>
> Sixthly, the surface of grazing and crop lands that would be unavailable in Europe – depending on the nuclear power plant – would represent between 16,000 to 37,000 km2 – in comparison with Switzerland's surface area (41,285 km2).[1405]

In particular the safety of Beznau-1, the eldest of the Swiss reactors, continues to raise concerns. In November 2019, two senior nuclear experts with respectively 35 and 25 years of experience at the German Öko-Institut and both members of various advisory government committees, released an assessment of the safety case of the Beznau-1 reactor pressure vessel prior to its restart after a three-year outage (see previous WNISR editions for details). Their judgement is severe: wrong measuring technology, innovative, untested and unqualified methodology to prove origin of defects and numerous uncertainties in the Swiss Federal Nuclear Safety Inspectorate's (ENSI) conclusion that over 3,000 discovered material defects would not have any effect on the embrittlement of the vessel.[1406]

ENSI replied half a year after the publication and claimed the Öko-Institut study would be containing "gross mistakes and false statements" and postulated that "the reactor pressure vessel of the nuclear power plant Beznau-1 is safe".[1407] It is precisely the absolute nature of the ENSI judgement that the Öko-Institut experts question in their response:

> The reactor pressure vessel of a nuclear power plant must not fail. (…) The reactor pressure vessel [RPV] however shows a high level of embrittlement and, in addition, material defects.

1403 - SFOE, "Schweizerische Elektrizitätsstatistik 2019/Statistique Suisse de l'Électricité 2019", op. cit.

1404 - UVEK/DETEC, "Bundesrat will einheimische erneuerbare Energien stärken und Strommarkt öffnen", 3 April 2020, Federal Department of the Environment, Transport, Energy and Communications, see https://www.uvek.admin.ch/uvek/de/home/uvek/medien/medienmitteilungen.msg-id-78665.html, accessed 3 August 2020.

1405 - Frédéric-Paul Piguet et al., "Modeling of a Major Accident in Five Nuclear Power Plants From 365 Meteorological Situations in Western Europe and Analysis of the Potential Impacts on Populations, Soils and Affected Countries", Institut Biosphère, Geneva, 27 August 2019.

1406 - Simone Mohr and Christian Küppers, "Materialfehler im hochversprödeten Reaktordruckbehälter des Kernkraftwerks Beznau Block 1— Stellungnahme zum Sicherheitsbericht der Axpo, zum Review des ENSI und zum Assessment des IRP bezüglich des Sicherheitsnachweises des Reaktordruckbehälters von Beznau 1", commissioned by Greenpeace Switzerland and SES, 28 June 2019; also Simon Banholzer, "Öko-Institut zweifelt am Sicherheitsnachweis von Beznau I", SES, 6 November 2019 (in German), see https://www.energiestiftung.ch/medienmitteilung/oeko-institut-zweifelt-am-sicherheitsnachweis-von-beznau-i.html, accessed 10 August 2020.

1407 - ENSI, "NGO-Kritik am KKW Beznau ist unhaltbar", Eidgenössisches Nuklearsicherheitsinspektorat, 4 June 2020, see https://www.ensi.ch/de/2020/06/04/ngo-kritik-am-kkw-beznau-ist-unhaltbar/, accessed 10 August 2020.

> Furthermore, a methodology and approaches were chosen for the safety case, which have been implemented for the first time worldwide.[1408]

Therefore, the experts say, the comprehensibility of the assessment needs to be fully guaranteed for third parties, which is not the case.

Meanwhile, Switzerland continues to struggle with the implementation of a credible independent national nuclear regulator. On 24 June 2020, Martin Zimmermann resigned from his position as Chairman of the Board of the national safety authority ENSI as of the end of the month. His decision was "triggered by accusations of a lack of independence that have been expressed in the media as well as in procedural requests", according to a statement by the ENSI Board.[1409] Ten days earlier, the online service *Infosperber* had revealed that the top nuclear safety official had been an active member of the Nuklearforum, "the propaganda organization of the nuclear lobby" between 2017, when he was first appointed to the ENSI board and 1 January 2020, when he took the Chair.[1410] He had not disclosed the membership to the Energy Ministry prior to his nomination. The demonstrated lack of independence led to two parliamentary initiatives and an NGO-driven public outcry, leaving little choice for Zimmermann but to step down. The *Berner Zeitung* gave it the headline "And Again the Highest Nuclear Watchdog Resigns", as in 2011, a predecessor of Zimmermann had to leave—for the same reason.[1411]

In a December 2019 paper, the Swiss Energy Foundation (SES) analyzed the drivers for the Mühleberg closure and the continued operation of the other four reactors. It concludes that while the Mühleberg owners soon after 3/11 had developed a strategy to abandon their unit, the other nuclear utilities' strategies never considered a nuclear phase-out as a potential goal. "However, today, only the hope for higher power prices appear to justify this strategy," the authors conclude.[1412]

United Kingdom

See United Kingdom Focus.

1408 - Öko-Institut e.V., "Stellungnahme des Öko-Instituts zu den Kommentaren des ENSI vom 20.05.2020", 15 July 2020 (in German), see https://www.energiestiftung.ch/medienmitteilung/akw-beznau-ensi-weicht-zentraler-kritik-aus.html, accessed 10 August 2020.

1409 - ENSI, "Martin Zimmermann to stand down as Chairman of the ENSI Board at the end of June 2020", 25 June 2020, see https://www.ensi.ch/en/2020/06/25/martin-zimmermann-to-stand-down-as-chairman-of-the-ensi-board-at-the-end-of-june-2020/, accessed 6 August 2020.

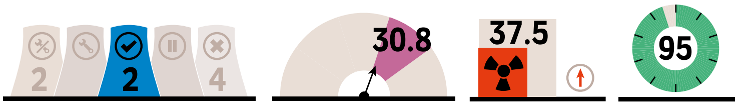
1410 - Kurt Marti, "Die atomare Vergangenheit des obersten Atomaufsehers", *Infosperber*, 15 June 2020 (in German), see https://www.infosperber.ch/Umwelt/Oberste-Atomaufsicht-Der-Bock-wird-zum-Gartner, accessed 6 August 2020.

1411 - Stefan Häne, "Zweifel an Glaubwürdigkeit – Und wieder tritt der oberste Atomaufseher zurück", *Berner Zeitung*, 25 June 2020 (in German), see https://www.bernerzeitung.ch/und-wieder-tritt-der-oberste-atomaufseher-zurueck-387124148865, accessed 6 August 2020.

1412 - Simon Banholzer et al., "Treiber für Stillegungsentscheide in der Schweizer Atomindustrie", SES, 18 December 2019.

CENTRAL AND EASTERN EUROPE

Bulgaria



In Bulgaria, nuclear power provided 15.9 TWh or 37.5 percent of the country's electricity in 2019, down from a maximum of 47.3 percent in 2002, which is produced by two VVER-1000 reactors at Kozloduy. Originally, there were six reactors on site, but the oldest four (VVER-440 v230) were closed as part of the agreement for Bulgaria to join the E.U. The two VVER-1000 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 an additional 10-year operating life, to enable it to continue operating until 2027, and in October 2019, Unit 6, was granted a license until 2029. It is reported that the total cost of the two-unit extension program was BGN292 million (US$163 million).[1413] In December 2019, the Russian fuel company TVEL announced that it 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.[1414]

There have been ongoing attempts since the mid-1980s to build another nuclear power plant at Belene in Northern Bulgaria, but so far, all of them failed. In March 2019, the Government announced that it was preparing to select a single strategic investor for the project and started a tender procedure[1415], which officially started after publication in the EU Official Journal. Initial interest has been expressed by China National Nuclear Corporation (CNNC) and Rosatom.

In December 2019 during a visit to the U.S. by Prime Minister Boyko Borisov conversations were held with President Trump about the construction of Belene, including the supply of turbines by American firms.[1416] The same month, the Bulgarian Government announced that five companies had been shortlisted for negotiations, namely CNNC, Korea Hydro & Nuclear Power (KHNP) and Rosatom's subsidiary Atomenergoprom, although Russia very much sees the project as its own. Two companies, Framatome and General Electric (GE) were shortlisted to supply either the project's turbine island (GE) or Instrumentation and Control – I&C (Framatome) rather than the whole reactor.

The finalists were expected to submit binding bids by the end of January 2020.[1417] The Government announced that investors would be able to negotiate electricity purchases with companies seeking to acquire minority stakes in Belene. At the end of the deadline, the director of the nuclear regulator held a press conference and stated that no application had been received from any company and that it would take months to review any application,

1413 - *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 14 April 2020.

1414 - *NEI*, "Russia to supply fuel to Kozloduy NPP until 2025", 5 December 2019, see https://www.neimagazine.com/news/newsrussia-to-supply-fuel-to-kozloduy-npp-until-2025-7541032/, accessed 14 April 2020.

1415 - Ministry of Energy, "Launch of the procedure for a strategic investor for 'Belene' NPP project", Press Release, Republic of Bulgaria, 11 March 2019, see https://www.me.government.bg/en/theme-news/startira-procedurata-za-izbor-na-strategicheski-investitor-po-proekta-aec-belene-2706-m0-a0-1.html, accessed 12 May 2020.

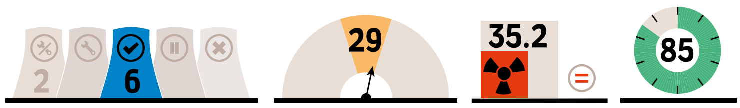
1416 - Gary Peach, "Newbuild. Bulgaria Forced to Balance US, Russian Interests", *NIW*, 6 December 2019.

1417 - *NIW*, "Weekly Roundup: Bulgaria Announces Finalists for Belene", 20 December 2020.

undermining the Government's previous claiming that the project could be licensed at the start of 2020.[1418]

The state has reserved the right to have a blocking minority in a future project company.[1419] However, as a result of the global pandemic the Government had been unable to fully access all the bids, with delays of at least a month expected, although *Reuters* reported that the Russian, Chinese and Korean bids were to include an investment pledge of €10 billion (US$10.7 billion) for the completion of the units, while the French and U.S. bids were to provide equipment as well as financing.[1420] However, questions have been raised as to the economic viability of the project, with electricity prices the lowest in Europe and the parliamentary decision prohibiting the state from granting such guarantees; therefore, without substantial changes, it is difficult to see how the project could proceed.[1421]

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 2019, nuclear plants generated 28.6 TWh or 35.2 percent of the electricity, practically equivalent to the 28.3 TWh or 34.5 percent in 2018.

The country was a net exporter of 13.1 TWh of electricity in 2019, equivalent to around half of the nuclear output, comparable to the output of Temelín. Czech electricity exports strongly increased to this level after Temelín was brought to the grid in 2000 and have been roughly stable ever since.

The Dukovany units were started up during 1985–87 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[1422], with a similar request granted for Unit 2 in July 2017 and for Units 3 and 4 in January 2018.

However, in February 2018, the head of the Czech State Office for Nuclear Safety, Dana Drábová,[1423] said that there was pressure from the EU to restrict the operation life of the reactors to 40 years.[1424] Furthermore, the fact that the lifetime extension was decided without an environmental impact assessment is contested by Czech and Austrian NGOs under the Espoo and Aarhus Conventions.

1418 - *NIW*, "Briefs – Bulgaria", 17 January 2020.

1419 - *NEI*, "Five companies shortlisted for Belene NPP", 24 December 2019, see https://www.neimagazine.com/news/newsfive-companies-shortlisted-for-belene-npp-7569814, accessed 26 December 2019.

1420 - Tsvetelia Tsolova, "Bulgaria delays deadline for Belene nuclear project bids", *Reuters*, 22 March 2020, see https://af.reuters.com/article/commoditiesNews/idAFL8N2BF0DR, accessed 22 March 2020.

1421 - Gary Peach, "Newbuild. Bulgaria Forced to Balance US, Russian Interests", *NIW*, 6 December 2019.

1422 - *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 15 May 2020.

1423 - ČEZ, "ČEZ Group Annual Report 2017", 2018, see https://www.cez.cz/edee/content/file/investori/vz-2017/vz-2017-en.pdf, accessed 15 May 2020.

1424 - *NEI*, "Czech Republic under European pressure over Dukovany", 26 February 2018, see http://www.neimagazine.com/news/newsczech-republic-under-european-pressure-over-dukovany-6065809/, accessed 15 May 2020.

This did not prevent ČEZ, the state-owned operator, from announcing three months later plans to prolong the lifetime of the Temelín power plant to 60 years.[1425]

Over the past two decades the Government and industry have announced new initiatives to build additional reactors, the most recent round of which was 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.[1426] In January 2019, special nuclear envoy Ján Štuller was replaced by former ČEZ CEO Jaroslav Míl[1427], followed by a government announcement in February 2019 that it was willing to give a contract to ČEZ to build further units at Dukovany, but without a guaranteed purchase price for electricity. On 13 November 2019, the Czech parliamentary committee for the construction of new nuclear resources approved the construction of the Dukovany-2 nuclear plant.[1428] 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.[1429]

Minister of Industry Karel Havlicek told reporters in February 2020 that by the end of 2022, the supplier should be selected.[1430] In March 2020, ČEZ submitted an application to the State Office for Nuclear Safety (SÚJB) for permission to construct two new 1200 MW units at the Dukovany site. In June 2020, the government announced that it had agreed a financing model whereby the government will provide a loan covering 70 percent of the project's approximate US$6 billion price tag, while CEZ will have to front the remaining 30 percent. The government said it was their intention to launch a tender later in 2020.[1431]

The government is expected to prepare 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 is 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.[1432] It is not yet clear how the contracts between the state and ČEZ will be drawn up to provide such guarantees to ČEZ and minority shareholders.

As with other European countries the COVID-19 pandemic has affected power consumption. Analysis from Carbon Brief suggests that during April 2020 power demand was down by

1425 - Chris Johnstone, "Czech power giant bolsters arguments for 60 year lifespan of nuclear plants", *Radio Praha*, 11 May 2018, see http://www.radio.cz/en/section/curraffrs/czech-power-giant-bolsters-arguments-for-60-year-lifespan-of-nuclear-plants, accessed 15 May 2020.

1426 - Jan Lopatka, "Czechs put off decision on building new nuclear plants", *Reuters*, 17 May 2018, see https://uk.reuters.com/article/uk-czech-nuclearpower/czechs-put-off-decision-on-building-new-nuclear-plants-idUKKCN1II2SD, accessed 15 May 2020.

1427 - *Prague Daily Monitor*, "Jaroslav Míl appointed Special Envoy for Nuclear Energy", 8 January 2019, see http://praguemonitor.com/2019/01/08/jaroslav-m%C3%Adl-appointed-special-envoy-nuclear-energy, accessed 15 May 2020.

1428 - *NEI*, "Czech Republic approves new unit for Dukovany", 18 November 2019, see https://www.neimagazine.com/news/newsczech-republic-approves-new-unit-for-dukovany-7513325/, accessed 18 April 2020.

1429 - *NIW*, "Briefs - Czech Republic", 15 November 2019.NIW, "Briefs – Czech Republic", 15 November 2019.

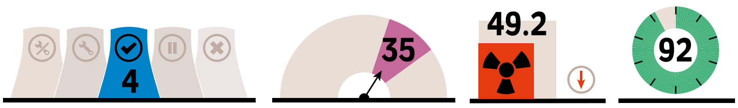
1430 - *NEI*, "ČEZ applies to build new nuclear units at Dukovany", 30 March 2020, see https://www.neimagazine.com/news/newscez-applies-to-build-new-nuclear-units-at-dukovany-7844971/, accessed 14 April 2020.

1431 - Gary Peach, "Prague Announces 70% Financing for Dukovany", *NIW*, 5 June 2020.

1432 - Phil Chaffee, "Prague Advances Dukovany Plans", *NIW*, 1 May 2020.

11 percent compared to the same period in 2019. This combined with higher production from renewables—in the Czech Republic and the EU as a whole—has further squeezed the market for fossil fuels and nuclear power.[1433] This increasingly challenges the economics of nuclear power, as, due to their inflexibility they cannot respond to price signals from the market and thus will continue to operate even when it is uneconomic to do so. In response to low power demand the outage from Dukovany-3 was extended.[1434]

Hungary



Hungary has one nuclear power plant, at Paks, where four VVER-440 v213 reactors provided a stable 15.4 TWh or 49.2 percent of the country's electricity in 2019. The nuclear share in the national power mix is down from 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 unit in 2014, the third in 2016 and the fourth in December 2017, enabling operation until the mid-2030s.

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.[1435] In February 2017, during a visit to Hungary, Russia's President Putin confirmed that it was willing to fund 100 percent of the estimated €12 billion (US$12.9 billion) investment.[1436] The Russian-Hungarian bilateral financing agreement proposed at the time consisted of a €10 billion (US$11.3 billion) loan to the Hungarian state, to be repaid starting in 2026, irrespective whether the project will be online at that time. Hungary itself will have to invest 20 percent or €2 billion (US$2.3 billion) into the project.

In November 2016, the European Commission cleared the award of the contract to Rosatom of any infringement on its procurement rules. In March 2017, the European Commission also approved the financial package for Paks II.[1437] However, in February 2018 the Austrian Government challenged the validity of the decision, which is still under review by the European Court of Justice.[1438] The legal challenge has subsequently been supported by the Luxembourg Government.

1433 - Dave Jones, "Analysis: Coronavirus has cut CO2 from Europe's electricity system by 39%", *Carbon Brief*, 29 April 2020, see https://www.carbonbrief.org/analysis-coronavirus-has-cut-co2-from-europes-electricity-system-by-39-per-cent, accessed 18 May 2020.

1434 - WNA, "COVID-19 Coronavirus and Nuclear Energy", 12 May 2020, see https://www.world-nuclear.org/information-library/current-and-future-generation/covid-19-coronavirus-and-nuclear-energy.aspx, accessed 18 May 2020.

1435 - Krisztina Than, "Special Report: Inside Hungary's $10.8 billion nuclear deal with Russia", *Reuters*, 30 March 2015, see https://www.reuters.com/article/us-russia-europe-hungary-specialreport-idUSKBN0MQ0MP20150330, accessed 15 May 2020.

1436 - *NIW*, "Briefs – Hungary", 3 February 2017.

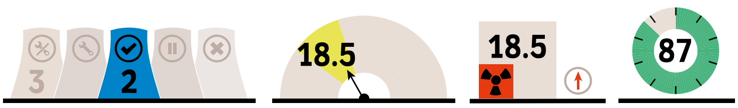
1437 - European Commission, "State Aid—Hungary—SA.38454 (2015/C) (ex 2015/N)— Possible aid to the Paks nuclear power station", Official Journal of the European Union, 12 January 2016, see https://publications.europa.eu/en/publication-detail/-/publication/669cd986-b8fd-11e5-8d3c-01aa75ed71a1/language-en, accessed 15 May 2020.

1438 - *WNN*, "Austria takes EC to court over Paks decision", 23 February 2018, see http://www.world-nuclear-news.org/NP-Austria-takes-EC-to-court-over-Paks-decision-2302184.html, accessed 15 May 2020.

The plant was granted an environmental license in September 2016, and in March 2017 the Hungarian Atomic Energy Authority approved the site license for the new construction.[1439] However, since then, there has 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.[1440]

In early 2018 reports suggested that a construction permit was expected by mid-2018[1441] and the project to be completed in 2024–2025. In June 2019, a ceremony was held with representatives of Rosatom to mark the start of the erection of buildings at the site.[1442] In October 2019, Rosatom handed over the project technical documents.[1443] On 30 June 2020, Paks II Ltd. submitted the construction license application to the Hungarian Atomic Energy Authority (HAEA). The regulatory procedure started its assessment the next day and HAEA has 12 months that can be extended by an additional three months to make known its views.[1444] If all did go according to plan, site preparation would take an additional 18 months, therefore construction is to start in mid-2022, some six years after the Hungarian and Russian Government signed the intergovernmental agreements. Power production is therefore likely to be in 2030, rather than the 2025 originally envisaged. It has been noted that neither government is pressing for the project to proceed. Russia, where the economy is suffering, awarded the project 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.[1445]

Romania



Romania has one nuclear power plant at Cernavoda, where two Canadian-designed CANadian Deuterium Uranium (CANDU) reactors are in operation. In 2019, they provided a stable 10.4 TWh or 18.5 percent of the country's electricity, compared to 20.6 percent in 2009.

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

1439 - *NIW*, "Briefs – Hungary", 31 March 2017.

1440 - Gary Peach, "Five Years on, Hungary's Paks Expansion Stumbles Along", *NIW*, 8 February 2019.

1441 - WNA, "Nuclear power in Hungary", Updated June 2019, see http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/hungary.aspx, accessed 15 May 2020.

1442 - Rosatom, "The first construction and installation work launches at the construction base of the Paks-2 NPP (Hungary)", Press Release, 20 June 2019, see https://www.rosatom.ru/en/press-centre/news/the-first-construction-and-installation-work-launches-at-the-construction-base-of-the-paks-2-npp-hun/, accessed 15 May 2020.

1443 - Tamas Szilagyi, "Hungarian government acknowledges delay at Paks nuclear power plant", *bne IntelliNews*, 20 November 2019, see http://www.intellinews.com/hungarian-government-acknowledges-delay-at-paks-nuclear-power-plant-171884/.

1444 - Hungarian Atomic Energy Authority, "Paks II. Ltd. submitted the construction license application to the HAEA", 30 June 2020, see http://www.oah.hu/web/v3/HAEAportal.nsf/web?OpenAgent&article=news&uid=5B9108F378B8DFBCC1258597003BF3DE, accessed 5 July 2020.

1445 - Gary Peach, "Exorbitant Costs, Solar Energy Remove Luster From Paks II", *NIW*, 22 May 2020.

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 in 2026.[1446]

As with other countries, the operation of Cernavoda has been affected by the COVID-19 pandemic and in April 2020, the planned overhaul of Unit 1 has been delayed. This would have been done during a planned maintenance which is performed every two years, during May and June and usually last 30 days. It is unclear when it will be undertaken now.[1447]

Various foreign companies have been involved in the attempts to revive the construction of Units 3, 4 and 5. The latest attempt was launched in cooperation with CGN, which signed a letter of intent in November 2013 with the Cernavoda operator, state-owned electricity producer Societatea Nationala Nuclearelectrica (SNN) to complete the projects in 2019 and 2020. This was followed in November 2015, with the signing of a Memorandum of Understanding (MoU) between Nuclearelectrica and CGN for the construction, operation and decommissioning of Units 3 and 4. The MoU also included agreements on investments, and, remarkably, CGN was to be the majority share owner of the project with at least 51 percent of the shares.[1448] In January 2016, the Romania Government formally expressed support for the project. The cost of the completion of two reactors with 720 MW each was expected to be US$7.8 billion.[1449] However, by late 2017, the Government admitted that negotiations needed to be restarted, with a hope that a binding investment agreement would be signed by February or March 2018,[1450] a deadline which has again been missed.

In January 2020 the Government announced that it would cancel the deal and Prime Minister Ludovic Orban stated, that "the partnership with the Chinese company is not going to work".[1451] Some of the reasons given for the collapse of the project are the increasing concerns in the U.S. about relations with China. Energy Minister Virgil Popescu highlighted the country's ties to both the U.S. and E.U. and said that the press in both places "abounds with information on the accusation of the Chinese company CGN for spying on the American territory".[1452]

The Government has not abandoned the project and is said to be looking for additional partners. 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. signed in August 2019.[1453]

1446 - *NEI*, "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 23 April 2020.

1447 - *SEE Energy News*, "Romania: Maintenance of NPP Cernavoda's unit 1 postponed", *Serbia SEE Energy Mining News*, 10 April 2020, see https://serbia-energy.eu/romania-maintenance-of-npp-cernavodas-unit-1-postponed/, accessed 18 May 2020.

1448 - *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 15 May 2020.

1449 - *WNN*, "Romania expresses support for China's role at Cernavoda", 25 January 2016, see http://www.world-nuclear-news.org/NN-Romania-expresses-support-for-China-role-at-Cernavoda-25011601.html, accessed 15 May 2020.

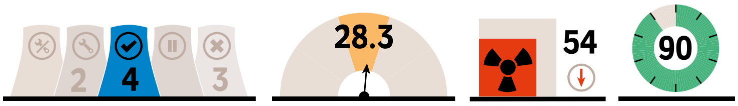
1450 - Phil Chaffee, "Romania: Can SNN end stalemate with CGN over Cernavoda ?", *NIW*, 22 September 2017.

1451 - *NEI*, "Romania Cancels China Deal on Cernavoda but Proceeds with Life Extension", 24 January 2020, op. cit.

1452 - Phil Chaffee, "Political Risk: CGN Faces Headwinds in Europe", *NIW*, 24 January 2020.

1453 - *NEI*, "Romania Cancels China Deal on Cernavoda but Proceeds with Life Extension", 24 January 2020, op. cit.

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 2019, their production increased to 14.3 TWh or 54 percent of the country's electricity, compared to 13.8 TWh and 55 percent in 2018.

The country has three permanently closed reactors at the Bohunice site. The A-1, a small 92 MW unit which started operation in 1972 was closed in 1977 following an accident. The other two VVER-440 v230 reactors were closed in 2006 and 2008, as part of an agreement by the G7 in Munich 1992 implemented in the agreement to join the European Union in 2004.

Units 1 and 2 at the Mochovce plant were started up in 1998 and 2000 respectively. 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, 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 (US$ $_{2007}$2.6 billion). 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.[1454]

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 winner of the bid, 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.[1455]

The construction project was beset with problems, and by May 2016, the estimate for the total costs of completion had risen to €5.1 billion (US$5.7 $_{2016}$ billion), with completion at the end of 2016/early 2017.[1456] In March 2017, SE announced a considerable further delay in the project with operation expected only at the end of 2018 and 2019 for Units 3 and 4, respectively. This is an additional two years of construction, while the officially expected cost increase was only €300 million (US$333 million).[1457] As of early 2018, completion of the projects was still expected at the end of 2018 and 2019 respectively.[1458] In June 2018, the Slovak Prime Minister himself raised doubts, if the latest schedule would be met, as he stated that "a number of problems

1454 - ENEL, "ENEL Starts Site Works at Mochovce 3–4", Press Release, Ente Nazionale per l'Energia Elettrica, 3 November 2008, see https://servizi.enel.it/eWCM/salastampa/comunicati_eng/1594888-1_PDF-1.pdf, accessed 15 May 2020.

1455 - *Reuters*, "Enel sells stake in Slovak power group, including nuclear plant, to EPH", 18 December 2015, see https://www.reuters.com/article/slovakia-enel-eph/enel-sells-stake-in-slovak-power-group-including-nuclear-plant-to-eph-idUSL8N14657L20151218, accessed 15 May 2020.

1456 - 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 15 May 2020.

1457 - *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 15 May 2020.

1458 - *NIW*, "Briefs–Slovakia", 16 February 2018.

arose during construction, and even now this makes us doubt whether this year's deadline for the third unit is realistic."[1459]

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$305 million) to the cost of the Mochovce-3 and -4 project, representing a 5 percent increase in costs, and bringing total costs to €5.4 billion (US$6.1 billion).[1460] However, in September 2019 it was announced that the Nuclear Regulatory Authority (UJD) would require further modifications prior to fuel loading.[1461] In January 2020 it was announced that the nuclear regulator had found two deficiencies in Unit 3 following a second round of hot testing. The regulator highlighted reduced insulation resistance in the four electric heaters of the pressurizer, and reduced air quality in the hermetic zone, "probably due to vapors from applied coatings." SE had to submit a plan for corrective action.[1462]

Fuel loading has been 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.[1463] However, this schedule must be in doubt, as due to social distancing measures the number of workers allowed on the site halved in March.[1464] The National regulator said that "it is impossible to estimate a precise delay for commissioning of the third nuclear unit. It will depend on the results of the ongoing inspections of the material and the extent of the measures that may be required."[1465] In June 2020, it announced a further of six month "extension of the period for decision in the administrative proceeding for authorization for commissioning of nuclear installation of the Unit 3 - NPP Mochovce".[1466] In June 2019, the TVEL Fuel Company, part of Rosatom, had agreed to fuel the Slovak reactors for the next five years, with the possibility of a contract extension to 2030.

On 15 April 2019, the Slovak anti-corruption police raided several SE offices, including those at Mochovce, and arrested the former CEO of Slovenské Elektrárne, Paolo Ruzzini, and Nicola Cotugno, former Mochovce director and Ruzzini's successor at SE on corruption charges. Both were involved in the privatization of SE to ENEL in 2004 and responsible for

1459 - *NIW*, "Slovakia: Are Mochovce's Headaches Over ?", 8 June 2018.

1460 - *WNN*, "Mochovce 3 completes commissioning test", 16 April 2019, see https://www.world-nuclear-news.org/Articles/Mochovce-3-completes-commissioning-test, accessed 15 May 2020.

1461 - *NEI*, "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 23 April 2020.

1462 - *NIW*, "Briefs - Slovakia", 31 January 2020.

1463 - Slovenske Elektrarne, "Mochovce 3: Nuclear authority issued a draft decision on fuel loading", 18 February 2020, see https://www.seas.sk/article/mochovce-3-nuclear-authority-issued-a-draft-decision-on-fuel-loading/409, accessed 23 April 2020.

1464 - *vEnergetike*, "Completion of Mochovce NPP may be delayed again", *Webnoviny.sk*, 18 May 2020, see https://www.webnoviny.sk/venergetike/completion-of-mochovce-npp-may-be-delayed-again/, accessed 27 June 2020.

1465 - vEnergetike.sk, "Mochovce NPP will be delayed, UJD confirms", 26 May 2020, see https://www.webnoviny.sk/venergetike/mochovce-npp-will-be-delayed-ujd-confirms/, accessed 9 June 2020.

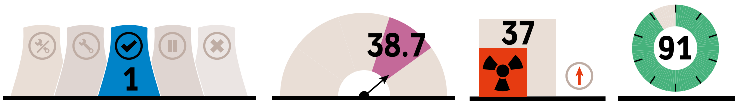
1466 - UJD, "Announcement of the Nuclear Regulatory Authority of the Slovak Republic on the extension of the period for decision in the administrative proceeding for authorization for commissioning of nuclear installation of the Unit 3 - NPP Mochovce", Press Release, Nuclear Regulatory Authority of the Slovak Republic, 16 June 2020, see https://www.ujd.gov.sk/ujd/www1.nsf/$All/4188834860C1B178C125858B002981AB, accessed 7 August 2020.

the restart of the Mochovce-3 and -4 construction.[1467] Another raid was undertaken 1 year later, in March 2020, when the national criminal agency entered the Mochovce site looking into a discrepancy between the "composition, manufacturing process or origin" of certain components at the reactors and their documentation, relating to one pipe subcontractor. However, the press reported concerns the investigation could spread to other suppliers, further delaying startup.[1468]

In addition to the delays and cost overruns, concerns have been raised about the state of the power market, with power prices currently at €20–25/MWh (US$21–27/MWh) and electricity demand following the sluggish economy and the short- and medium-term impact of COVID-19 pandemic. It is expected that, if and when the Mochovce units are completed, their capacity will mainly be used for export, so given the low electricity prices in the European market, the chance that SE will recover their ever-increasing investment seems slim. According to SE, by December 2019, Unit 3 was 99.3 percent complete and Unit 4 stood at 87.1 percent.[1469]

The accession to the Presidency in June 2019 of public interest lawyer Zuzana Čaputová and a landslide change in government in 2020 shed more doubt on how further investments in the project are to be financed. After the elections held on 29 February 2020, the new Slovak government is composed of four political parties. With exception of the party Sloboda and Solidarita, the remaining three parties have not been part of a government before and therefore are less associated with previous corruption schemes. All four parties support the completion of the Mochovce but have mixed positions about further new nuclear projects. The largest political party, Ol'aNO (Obyčajní L'udia a nezávislé osobnosti), aims to amend the current "non-transparency particularly/only in the nuclear sector".[1470] Čaputová is a recipient of the prestigious Goldman Environmental Prize (2016)[1471] for her successful campaigning against a major waste dump.

Slovenia



Slovenia jointly owns the Krsko nuclear power plant with Croatia—a 696-MW Westinghouse PWR. In 2019, it provided a stable 5.5 TWh or 37 percent of Slovenia's electricity, a nuclear share well below the maximum of 42.4 percent in 2005.

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 life to 60 years, so that it would continue until 2043, as well as to construct a dry storage facility for the spent fuel. In

1467 - Finweb, "NAKA na letisku zadržala exšéfa Slovenských elektrární. Preverujú podozrenia týkajúce sa Mochoviec", 15 April 2019 (in Slovak), see https://finweb.hnonline.sk/ekonomika/1924600-naka-na-letisku-zadrzala-exsefa-slovenskych-elektrarni-preveruju-podozrenia-tykajuce-sa-mochoviec, accessed 15 May 2020.

1468 - Phil Chaffee, "Slovakia: Police Raid Mochovce New Build", *NIW*, 6 March 2020.

1469 - Slovenské elektrárne, "Mochovce 3 & 4 Construction - as of 31 December 2019", Undated, see "Mochovce 3 and 4 Project Completion", 29 April 2018, see https://www.seas.sk/mochovce-3-4-npp, accessed 15 May 2020.

1470 - Centre for Sustainable Alternatives, "Where do new government parties stand on nuclear in Slovakia?", Nuclear Transparency Watch, April 2020, see http://www.nuclear-transparency-watch.eu/wp-content/uploads/2020/04/Positions_of_Slovak_political_parties.pdf, accessed 8 September 2020.

1471 - For more information: The Goldman Environmental Prize, "Zuzana Čaputová—2016 Goldman Prize Recipient", Undated, see https://www.goldmanprize.org/recipient/zuzana-caputova/, accessed 13 June 2020.

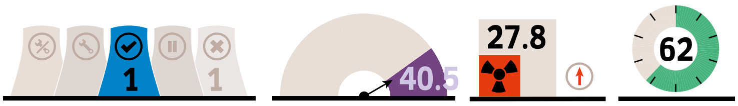
May 2016, a spokeswoman for the operator NEK (Nuklearna Elektrarna Krško) said: "The lifespan of Krsko has been extended providing that the plant passes a security check every 10 years with the next checks due in 2023 and 2033."[1472] In 2018, the operator announced around €50 million (US$57 million) worth of investment being planned for 2019, mostly for completing safety upgrades and replacing obsolete equipment.[1473] The first outage for this was undertaken in October 2019, with the next scheduled for April 2021, when work is expected to be completed.[1474] This life-time extension was carried out without a prior environmental impact assessment or public participation, in spite of a court order to carry out such an assessment. It is currently unclear whether this has any implications.

As part of the co-ownership, Croatia is partly responsible for waste management and its preferred location for storage of the material produced by the Krsko plant is proving controversial with its neighbors as it is only 1 km from its border with Bosnia and Herzegovina whose Foreign Minister, in April 2020, characterized the proposal as unacceptable.[1475]

In January 2010, an application was made by the nuclear operator to the Ministry of Economy to build an additional unit, but no advancement of the project has been reported ever since.

FORMER SOVIET UNION

Armenia



Armenia has one remaining reactor at the Metsamor nuclear power plant, situated within 30 kilometers of the capital Yerevan. Armenian-2 provided 2 TWh or 27.8 percent of the country's electricity in 2019, about half of the maximum nuclear share of 45 percent in 2009. Armenia has the lowest lifetime load factor of any nuclear country in the world, averaging 53.6 percent; in 2019, the load factor was a still modest 61.5 percent.

The reactor started generating electricity 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 led to significant power shortages, which led to the Government's decision in 1993 to re-open Unit 2 at Metsamor. Since 2003, the Metsamor plant is operated by InterRAO, a subsidiary of Russian Rosatom, as a part of an arrangement to repay debts to Rosatom's TVEL fuel supplier.[1476]

1472 - *NEI*, "Life extension for Slovenia's Krslo NPP", 6 May 2016,
see http://www.neimagazine.com/news/newslife-extension-for-slovenias-krslo-npp-4885976/, accessed 15 May 2020.

1473 - *The Slovenia Times*, "Krško nuclear plant operating efficiently, upgrades planned", 27 November 2018,
see http://www.sloveniatimes.com/krsko-nuclear-plant-operating-efficiently-security-upgrade-on-track, accessed 15 May 2020.

1474 - *NEI*, "Upgrading Krsko", 15 April 2020, see https://www.neimagazine.com/features/featureupgrading-krsko-7874556/, accessed 23 April 2020.

1475 - Igor Todorovic, "BiH warns Croatia against storing nuclear waste from Krško at border", *Balkan Green Energy News*, 3 April 2020, see https://balkangreenenergynews.com/bih-warns-croatia-against-storing-nuclear-waste-from-krsko-at-border/, accessed 23 April 2020.

1476 - WNA, "Nuclear Power in Armenia", Updated April 2020,
see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/armenia.aspx, accessed 28 May 2020.

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.[1477] 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.[1478] In June 2020, the Government, citing economic considerations, said it would only be using 60 percent of the US$270 million of the loan available.[1479]

In June 2016, the European Nuclear Safety Regulators Group (ENSREG) issued the "EU Peer Review Report of the Armenian Stress Tests"[1480] 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."[1481] 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.[1482]

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.[1483] In March 2019, Prime Minister Nikol Pashinyan confirmed that there were no plans to close Metsamor and that "we will extend the lifecycle of the nuclear power station as long as possible, although it is clear that it cannot work forever."[1484]

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. The proposal notes that diversification of fuel supply is necessary, notably via renewable energy sources. 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".[1485]

1477 - *NEI*, "Armenian NPP to close for refurb", 21 March 2019,
see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023/, accessed 16 May 2020.

1478 - *NEI*, "Armenian NPP to close for refurb", 21 March 2019,
see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023/, accessed 16 May 2020.

1479 - *Azatutyun.am*, "Yerevan Snubs Russian Funding for Metsamor Nuclear Plant", *Asbarez*, 11 June 2020,
see http://asbarez.com/194683/yerevan-snubs-russian-funding-for-metsamor-nuclear-plant/, accessed 27 June 2020.

1480 - ENSREG, "EU Peer Review Report of the Armenia Stress Tests", June 2016, see http://www.ensreg.eu/sites/default/files/attachments/2016-07-20_4259241_armenia_stress_tests_report-_ensreg_template_final.pdf, accessed 16 May 2020.

1481 - 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://eeas.europa.eu/sites/eeas/files/eu-armenia_comprehensive_and_enhanced_partnership_agreement_cepa.pdf, accessed 16 May 2020.

1482 - Emin Avundukluoglu, "Turkey: CHP submits motion on Armenian nuclear plant", *Anadolu Agency*, 12 December 2019,
see https://www.aa.com.tr/en/environment/turkey-chp-submits-motion-on-armenian-nuclear-plant/1671672, accessed 23 April 2020.

1483 - *NEI*, "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 23 April 2020.

1484 - *NEI*, "Armenian NPP to Close for Refurb", 21 March 2019,
see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023/, accessed 18 Mai 2020.

1485 - European Commission, "Eastern Partnership policy beyond 2020, Reinforcing Resilience - an Eastern Partnership that delivers for all", 18 March 2020.

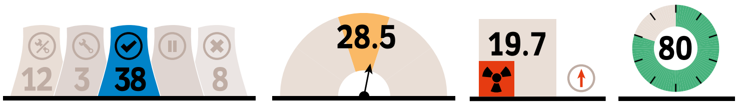
In early June 2019, Armenia's reactor was shut down for substantial repair and upgrade, during an outage that was scheduled to last for 110 days.[1486] In July 2019, the country experienced widespread blackouts as a result of a drop in the grid frequency.[1487] Metsamor has generated power in the first half of 2020, but it is unclear when it returned to service.

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. Since then, little progress has been made, and there is no clear choice on future technologies, with some proposing the development of Small Modular Reactors (SMRs).[1488]

Belarus

See Potential Newcomer Countries: section on Belarus.

Russia



In 2019, nuclear energy contributed 19.7 percent to the country's electricity mix with another record production of 195.6 TWh of electricity as new reactors have come online.

However, the past year has been mixed for the Russian nuclear industry. On the one hand, the grid connection of Novovoronezh 2-2 occurred on 1 May 2019[1489] with commercial operation starting on 1 November 2019[1490]; and the grid connection of the two reactors of the floating nuclear power plant, the Akademik Lomonosov, took place in December 2019 with commercial operation starting on 22 May 2020[1491]. Consequently, as of mid-2020, 38 reactors are operating in the Russian Federation and eight are permanently closed.

On the other hand, Russian society has been significantly impacted by the COVID-19 pandemic and the nuclear sector is no different. Concerns were raised by the head of Rosatom about the spread of the virus in the three "nuclear cities" which host civil and military nuclear research.[1492] Rosatom has said that they are introducing additional measures in their nuclear power plants domestically and those being built abroad, to "minimise the negative impact this health crisis

1486 - *NEI*, "Armenian NPP to close for refurb", 21 March 2019, see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023, accessed 25 July 2020.

1487 - *RFE/RL*, "Power In Armenia 'Being Gradually Restored' After Massive Outages", *RadioFreeEurope/RadioLiberty*, 10 July 2019, see https://www.rferl.org/a/power-supply-in-armenia-being-gradually-restored-after-massive-outages/30047895.html, accessed 23 April 2020.

1488 - *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 16 May 2020.

1489 - *WNN*, "Novovoronezh II-2 starts pilot operation", 4 June 2019, see http://world-nuclear-news.org/Articles/Novovoronezh-II-2-starts-pilot-operation, accessed 16 May 2020.

1490 - *WNN*, "Second Novovoronezh II unit enters commercial operation ", 1 November 2019, see https://world-nuclear-news.org/Articles/Second-Novovoronezh-II-unit-enters-commercial-oper, accessed 28 May 2020.

1491 - *NEI*, "Akademik Lomonosov begins commercial operation", 25 May 2020, see https://www.neimagazine.com/news/newsakademik-lomonosov-begins-commercial-operation-7938482, accessed 28 May 2020.

1492 - Tom Balmforth, "Coronavirus threatens workforce in Russia's nuclear cities - Rosatom", *Reuters*, 28 April 2020, see https://www.reuters.com/article/health-coronavirus-russia-nuclear-idUSL5N2CG5CY, accessed 16 May 2020.

has on supply chains".[1493] However, there are reports of construction staff being affected in both Belarus and Bangladesh, which are likely to cause further delays in construction.

Three large reactors remain under construction, two units at the Kursk site and one at Leningrad 2-2. The Kursk reactors are 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 destined for export. At construction start of Unit 1 completion was scheduled for late 2023, and in April 2020, the first deputy director for construction claimed that the project was on schedule.[1494]

Construction started at Leningrad 2-2 in April 2010, with the reactor expected to begin commercial operation at the beginning of 2021,[1495] that is even longer than it took to build the first unit: ten years from construction start to commercial operation. In June 2020, Rosenergoatom announced that preparation work would begin for the construction of four new reactors, Units 3 and 4 at Leningrad 2, as well as two reactors at Smolensk.[1496]

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.[1497]

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.[1498] Even before this date, the budget for construction of new reactors was expected to be in 2018, 2019 and 2020, a modest 15.7 billion rubles (US$250 million), 16.6 billion rubles (US$260 million) and 17.7 billion rubles (US$280 million) respectively,[1499] which may explain the lack of new construction in Russia beyond Kursk 2.

The latest Federal Target Program envisages a 25–30 percent nuclear share in electricity supply by 2030, 45–50 percent by 2050 and 70–80 percent by the end of the century. According to the World Nuclear Association's (WNA) nuclear profile for Russia, from 2019, the Government

1493 - *WNN*, "Rosatom takes measures to protect workers from COVID-19", 30 March 2020, see https://www.world-nuclear-news.org/Articles/Rosatom-takes-measures-to-protect-workers-from-COV, accessed 16 May 2020.

1494 - *NEI*, "Russia's Kursk II on schedule", 14 April 2020, see https://www.neimagazine.com/news/newsrussias-kursk-ii-on-schedule-7872033/, accessed 23 April 2020.

1495 - *NEI*, "Nuclear island almost complete at Leningrad II-2", 4 April 2020, see https://www.neimagazine.com/news/newsnuclear-island-almost-complete-at-leningrad-ii-2-7854322, accessed 23 April 2020.

1496 - *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 27 June 2020.

1497 - *WNN*, "Russia to build 11 new nuclear reactors by 2030", 10 August 2016, see http://www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html, accessed 16 May 2020.

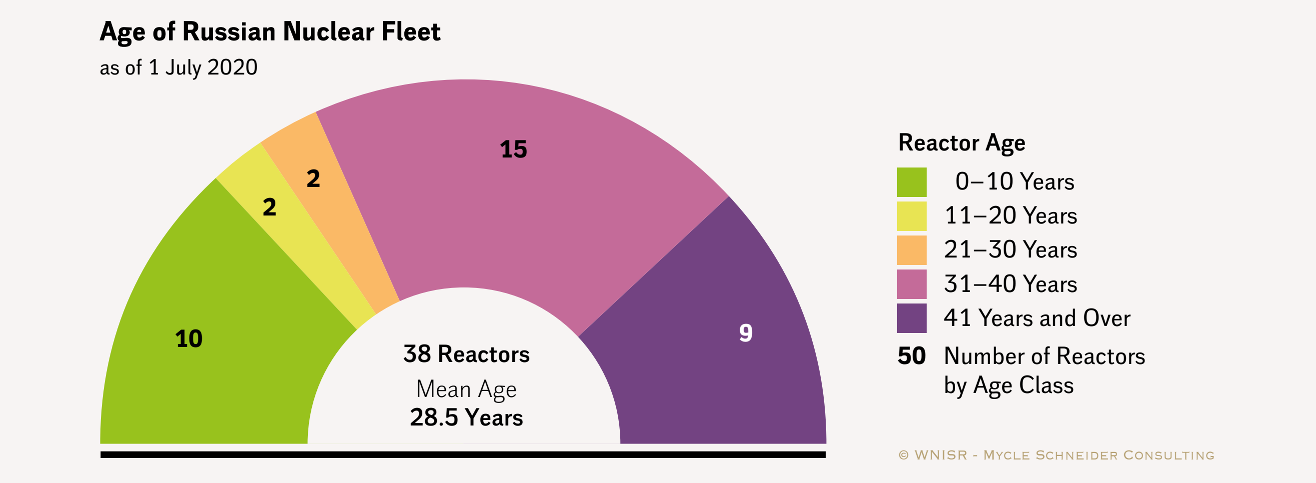
1498 - WNA, "Nuclear Power in Russia", Updated April 2020, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 23 April 2020.

1499 - *NIW*, "Briefs – Russia", 22 September 2017.

estimates that ten units will be completed by 2030, including the two completed Akademik Lomonosov reactors and the three reactors under-construction (Leningrad 2-2 and Kursk 2-1 and -2). Their list then includes two more reactors at Leningrad, two reactors at Smolensk and a fast reactor at Beloyarsk. However, it was reported that Rosatom received a budget of only 880 billion rubles (US$11 billion) and not the requested 1.16 trillion rubles ($US15.6 billion) for construction through to 2035. Startup of the fast reactor at Beloyarsk was delayed until 2036, from 2027, with no mention of the Smolensk units.[1500]

Russia has closed eight power generating reactors: Obninsk-1, Beloyarsk-1 and -2, Bilibino-1, Leningrad 1–1 and Novovoronezh 1–3. The average age of the Russian reactor fleet is now 28.5 years, with close to two thirds being 31 years or more, of which nine over 40 (see Figure 68). Therefore, a key issue for the industry is how to manage its aging units.

Figure 68 · Age Distribution of the Russian Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2020

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. 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[1501], while the VVER 1000s are expected to work for up to 50 years. Consequently, the closure of Leningrad 1–1 is potentially a significant event, as, after 46 years of operation, it would indicate that 60-year operational life is beyond the RMBK potential, and, if applied across the fleet, would lead to the closure of 10 of the remaining 13 operating RBMKs in the coming decade.

The country also has two 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 life of 30 years. This was once again extended in April 2020 for a further five years to enable the unit to

1500 - *WNN*, "Rosatom postpones fast reactor project, report says", 13 August 2019, see http://world-nuclear-news.org/Articles/Rosatom-postpones-fast-reactor-project-report-say, accessed 13 August 2019.

1501 - *NEI*, "Russia permanently closes Novovoronezh 3", 4 January 2017, see http://www.neimagazine.com/news/newsrussia-permanently-closes-novovoronezh-3-5709099/, accessed 15 May 2020.

operate until 2025.[1502] 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, 36 separate projects including; Bangladesh (two reactors at Rooppur); Belarus (two at Ostrovets); China (two at Tianwan and two in the Liaoning province); Egypt (four at El Dabaa); Finland (one at Hanhikivi); Hungary (two at Paks); India (four at Kudankulam); Iran (two at Bushehr) and Turkey (four at Akkuyu).[1503] Alexey Likhachyov, head of Rosatom, expects that by 2030, up to 70 percent of their revenue will come from outside the country. Likhochyov 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.[1504] However, the WNISR considers of these only nine reactors as under construction (two each in Bangladesh, Belarus, India and Turkey and one in Iran). Nervous of the logistical and transport challenges that these multiple construction projects will bring, Rosatom in early 2020 purchased a 30 percent share in Delo, a Russian logistics firm, which had recently bought a 50 percent share in Russia's largest cargo container shipper Trans/Container. This is likely to give Rosatom priority access to both rail and ship transportation.[1505]

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 COVID-19 pandemic has had a significant impact on global oil and gas prices, which in turn has a major impact on the Russian economy. The oil and gas production represents nearly 40 percent of the Russian state income and the collapse of prices will significantly affect the state budget on the short term. However, as worrying for the Russian economy will be the medium and long term of the pandemic on oil demand and therefore price. Therefore, the poor economic situation in Russia and the rise of national developers from China with greater access to capital are likely to undermine Rosatom's dominance of the very limited export market.

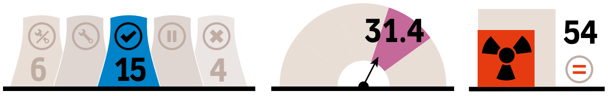
1502 - *NIW*, "Briefs–Russia", 3 April 2020.

1503 - Rosatom, "Projects", Undated, see http://www.rosatom.ru/en/investors/projects/, accessed 16 May 2020.

1504 - *Nuclear-news*, "Russia's nuclear company Rosatom on a drive to sell nuclear technology overseas", 25 June 2019, see https://nuclear-news.net/2019/06/25/russias-nuclear-company-rosatom-on-a-drive-to-sell-nuclear-technology-overseas/, accessed 16 May 2020.

1505 - Gary Peach, "Rosatom Invests in Transport, Charts 'Lessons Learned'", *NIW*, 7 February 2020.

Ukraine



Ukraine has 15 operating reactors, two of the VVER-440 design and the rest VVER-1000s. They provided 78.1 TWh or 54 percent of power generation in the country in 2019, a small increase from the previous year with 79.5 TWh or 53 percent. Output is expected to decrease in 2020 due to the COVID-19 pandemic. In April 2020, Energoatom withdrew three of its plants from service following a plunge in power demand.[1506] In response to the pandemic, special measures were taken to restrict the movement around the country's nuclear power plants with critical operational personnel housed in hotels near the power plants.

Twelve out of Ukraine's 15 reactors were completed in the late 1970s and 1980s and had an original design lifetime of 30 years. Ukraine has carried out a safety upgrade program for all of 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 contribute €600 million (US$670 million) between them.

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 (also spelled Rivne) have been granted a lifetime extension of 20 years,[1507] two units at South Ukraine for ten years, and four units at Zaporozhye for ten years[1508].

The IAEA completed a Pre-SALTO (Safety Aspects of Long-Term Operation) peer review mission at the third unit of the South Ukraine plant in April 2018 and concluded that the "plant has made progress in the field of ageing management" but noted that it had only "initiated many activities to prepare for safe LTO [long term operation]". The initial IAEA report also concluded: "The plant has developed a catalogue of operational defects in heat exchanging tubes in the steam generators".[1509]

The lifetime extension of Rovno-1 and -2 (or Rivne) is part of an ongoing controversy within the Espoo Convention on transboundary Environmental Impact Assessment (EIA), which concluded that Ukraine was in non-compliance for not executing an EIA before it decided to prolong the lifetime of these VVER440 reactors beyond their original technical lifetime of 30 years.[1510] Environmental groups in Ukraine have called upon European institutions to stop the support for "risky" life extension programs.[1511] The intermediary session of the Meeting

1506 - *WNN*, "Ukraine prepares to reduce output during pandemic", 30 April 2020, see https://world-nuclear-news.org/Articles/Ukraine-prepares-to-reduce-output-during-pandemic, accessed 16 May 2020.

1507 - *NEI*, "Life extension for Ukraine's Rovno 3", 23 July 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-rovno-3-6258731/, accessed 16 May 2020.

1508 - *NEI*, "Life extension for Ukraine's Zaporozhye 4", 16 October 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-zaporozhye-4-6803714/, accessed 16 May 2020.

1509 - IAEA, "IAEA Concludes Long-Term Operational Safety Review at South Ukraine Nuclear Power Plant", Press Release, 25 April 2018, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-south-ukraine-nuclear-power-plant, accessed 16 May 2020.

1510 - UNECE, "EIA/IC/CI/4 Ukraine – Information on matters considered by the Committee", Undated, see http://www.unece.org/environmental-policy/conventions/environmental-assessment/areas-of-work/review-of-compliance/committee-initiative/eiaicci4-ukraine.html, accessed 16 May 2020.

1511 - Iryna Holovko, "Time for Europe to stop Ukraine's nuclear energy sector", *Energy Post*, 18 May 2016, see http://energypost.eu/time-europe-stop-supporting-ukraines-risky-nuclear-power-sector/, accessed 16 May 2020.

of the Parties to the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) adopted a decision in February 2019 that "despite the positive steps taken, Ukraine remains in non-compliance with its obligations under the Convention" regarding the Rovno life-extension projects.[1512] In April 2017, the Ukrainian Ministry of Environment had sent an official notification to neighboring countries on the start of the EIA for the lifetime extension of South Ukraine and at Zaporozhye.[1513]

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. Building work started in 1986 and 1987 but stopped in 1990. In September 2015, the Ukrainian Parliament voted to cancel the project.[1514] In January 2017, the Russian Government confirmed that the 2011-agreement on the completion of the units had been canceled.[1515] Subsequently, Skoda JS has been appointed as the main supplier for the completion of the reactors and an EIA procedure has begun.[1516] As part of the Espoo Convention, in the spring of 2019, the Austrian Government sent documents on the potential environmental impact, with a comment period, for Governments and citizens until early May 2019.[1517] Despite this initiation of the EIA processes, there seems little chance that construction will restart in the near term.

In November 2019, Prime Minister Alexei Goncharuk sacked Yuri Nedashkovsky, head of Energoatom. Three reasons were given for the dismissal, "the deterioration of Energoatom's performance, the increase in the number of negative incidents and a procurement investigation with which the deputy of the previous convocation is associated." [1518] Energoatom later added that he had been fired because of inefficient management, suspicion of embezzlement of state funds, and mismanagement of procurement. The statement said procurement problems had led to defective products being used at nuclear plants.

In August 2017, the Government adopted an energy strategy which aims to maintain the current level of nuclear in the power mix of about 50 percent up to 2035, while at the same time to halve the level of energy intensity in the economy and increase the contribution of renewables to electricity to 25 percent (excluding hydro with 13 percent).[1519] The Government is also considering the future use of SMRs, with Holtec International, Ukraine's Energoatom and

1512 - UNECE, "Decision IS/1g – Compliance by Ukraine with its obligations under the Convention in respect of extension of the lifetime of the Rivne nuclear power plant", Excerpt from ECE/MP.EIA/27/Add.1 - ECE/MP.EIA/SEA/11/Add.1, February 2019, see http://www.unece.org/fileadmin/DAM/env/eia/meetings/2019/IS_MOP_5-7_February_2019__Geneva/Decision_IS.1g.pdf, accessed 16 May 2020.

1513 - Resource and Analysis Center 'Society and Environment', "Ukraine starts transboundary environmental impact assessment for nuclear power plants", Press Release, 19 April 2017, see http://www.rac.org.ua/en/for-media/press-releases--comments/19042017-ukraine-starts-transboundary-environmental-impact-assessment-for-nuclear-power-plants, accessed 16 May 2020.

1514 - Ed Adamczyk, "Ukraine scraps nuclear reactor deal with Russia", *UPI*, 16 September 2015, see https://www.upi.com/Top_News/World-News/2015/09/16/Ukraine-scraps-nuclear-reactor-deal-with-Russia/9811442413199/, accessed 16 May 2020.

1515 - *NEI*, "Russia ends Khmelnitsky construction agreement with Ukraine", 13 January 2017, see http://www.neimagazine.com/news/newsrussia-ends-khmelnitsky-construction-agreement-with-ukraine-5718894/, accessed 16 May 2020.

1516 - Ministry of Ecology and Natural Resources of Ukraine, "Notice on activities to be assessed for environmental impact", 2017, see http://eia.menr.gov.ua/uploads/documents/332/reports/10f33f0f9340fb1cd06c16c7bcc24950.pdf, accessed 16 May 2020.

1517 - Environment Agency Austria, "UVP KKW Khmelnitsky 3&4", Public Consultation Documents, 2019, see http://www.umweltbundesamt.at/umweltsituation/uvpsup/espooverfahren/espoo_ukraine/kkwkhmelnitsky34/, accessed 16 May 2020.

1518 - *NEI*, "Ukraine dismisses head of Energoatom reflecting political tensionsl", 2 December 2019, see https://www.neimagazine.com/news/newsukraine-dismisses-head-of-energoatom-reflecting-political-tensions-7534772/, accessed 23 April 2020.

1519 - *NEI*, "Ukraine reveals new energy strategy", 28 August 2017, see http://www.neimagazine.com/news/newsukraine-reveals-new-energy-strategy-5910630/, accessed 15 May 2020.

the country's State Scientific and Technology Centre (SSTC) entering a formal partnership to advance the U.S. company's SMR-160 for deployment.[1520] The SMR-160 remains under development and no country in the world has licensed the design yet. In March 2020, Energy Minister Oleksiy Orzhel, who was formerly head of the Energy Sector Better Regulation Office and head of the Ukrainian Association of Renewable Energy, was fired. It has been suggested that the dismissal was due to the Minister's apparent favor of renewable energy and his disdain for coal and nuclear power.[1521]

Proposals are now 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), is to be carried out in the form of a public-private partnership between the Ukrainian state and an investor consortium consisting of Westinghouse Electric Sweden, Luxembourg-based Polish Polenergia International, and U.K.-based EDF Trading.[1522] Ukraine is already exporting electricity to Hungary, Romania and Slovakia through the Burshtyn 'energy island' and to Poland and Moldova, while also importing electricity from Russia and Belarus. The Khmelnitsky project foresees electricity export in two ways: via the 750kV transmission line to Rzeszów in Poland and the line to the Albertirsa substation in Hungary. Upgrading work on these lines would enable the addition of 1000 MWe of nuclear power to the existing export potential of Burshtyn Energy Island.[1523]

The Ministry of Energy is also considering other means to consume the excess electricity in the country including cryptocurrency mining and the creation of data centers near nuclear power plants, with a pilot project connected to the Zaporozhye nuclear power plant.[1524]

1520 - *WNN*, "Consortium established for SMR-160 deployment in Ukraine", 12 June 2019, see https://www.world-nuclear-news.org/Articles/Consortium-established-for-SMR-160-deployment-in-U, accessed 28 May 2020.

1521 - Gary Peach, "Ukraine, Is Nuclear at a Crossroad ?", *NIW*, 27 March 2020.

1522 - 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 27 June 2020.

1523 - *WNN*, "Energoatom awaits approval for energy bridge tender", 18 April 2018, see http://www.world-nuclear-news.org/NP-Energoatom-awaits-approval-for-energy-bridge-tender-18041801.html, accessed 15 May 2020.

1524 - *Interfax Ukraine*, "Cryptomining is modern tool to remove surplus of electricity – Energy ministry", 7 May 2020, see https://en.interfax.com.ua/news/economic/660620.html, accessed 7 May 2020.

ANNEX 2 - STATUS OF CANADIAN NUCLEAR FLEET

Table 22 · Status of Canadian Nuclear Fleet - PLEX and Expected Closure

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	01/01/23–30/06/26		
Bruce-4		1978	01/01/25–31/12/27		
Bruce-5		1984	01/07/26–30/06/29		
Bruce-6		1984	01/01/20–19/10/23		
Bruce-7		1986	01/07/28–30/06/31		
Bruce-8		1987	01/07/30–30/06/33		
Darlington-1	OPG	1990	15/10/21–25/12/24	2055	2025
Darlington-2		1990	10/16–15/02/20[d]		
Darlington-3		1992	15/02/20–15/06/23[e]		
Darlington-4		1993	01/05-23–31/05/26		
Pickering-1	OPG	1971		2022[f]	2028[g]
Pickering-4		1973		2022[f]	
Pickering-5		1982		2024	
Pickering-6		1983		2024	
Pickering-7		1984		2024	
Pickering-8		1986		2024	
Point Lepreau	NB Power	1982	03/2008–03/2012	2040[h]	2022

Sources: Compiled by WNISR, from IESO, Operators, CNSC, 2020

Notes:

OPG = Ontario Power Generation.

a - IESO, "Annual Planning Outlook - A view of Ontario's electricity system needs", January 2020, see http://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Jan2020.pdf?la=en, accessed 1 August 2020.

b - As announced by operator.

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 - As of July 2020, refurbishment of Darlington-3 is expected in Q3 2020 with completion in Q4 2026, see OPG, "Darlington Refurbishment", n.d., see https://www.opg.com/strengthening-the-economy/our-projects/darlington-refurbishment/, accessed 1 August 2020.

f - Pickering-1 and -4 are expected to be closed in 2022. Recent announcements suggest that Ontario Power Generation and the Ontario government support continuing operating Units 1 and 4 till the end of 2024 and run Units 5 to 8 until the end of 2025; see *DurhanRegion.com*, "Ontario government supports extending Pickering nuclear station's lifespan", 16 August 2020, see https://www.durhamregion.com/news-story/10138629-ontario-government-supports-extending-pickering-nuclear-station-s-lifespan/, accessed 7 September 2020.

g - The Pickering Power Plan is licensed to 2028 but operation beyond 2024 would require additional authorizations, see https://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm?pedisable=true)

h - 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.

ANNEX 3 - STATUS OF JAPANESE NUCLEAR FLEET

Table 23 · Status of Japanese Nuclear Reactor Fleet (as of 1 July 2020)

Operator	Reactor	MW	Startup Year	Age Years	Shutdown		NRA Compliance[b]		Status
					Date[a] dd/mm/yy	Duration	Application dd/mm/yy	Approval dd/mm/yy	
CHUBU	Hamaoka-3 (BWR)	1 056	1987	33.4	29/11/10	9.6	16/06/15		LTO
	Hamaoka-4 (BWR)	1 092	1993	27.4	13/05/11	9.1	14/02/14[c]		LTO
	Hamaoka-5 (BWR)	1 325	2004	16.2	14/05/11	9.1			LTO
CHUGOKU	Shimane-2 (BWR)	789	1988	32.0	27/01/12	8.4	25/12/13		LTO
HEPCO	Tomari-1 (PWR)	550	1988	31.6	22/04/11	9.2	08/07/13		LTO
	Tomari-2 (PWR)	550	1990	29.8	26/08/11	8.8	08/07/13		LTO
	Tomari-3 (PWR)	866	2009	10.6	05/05/12	8.2	08/07/13		LTO
HOKURIKU	Shika-1 (BWR)	505	1993	27.5	01/03/11	9.3			LTO
	Shika-2 (BWR)	1 108	2005	15.0	11/03/11	9.3	12/08/14		LTO
JAPCO	Tokai-2 (BWR)	1 060	1978	42.3	11/03/11	9.3	20/05/14	Second Stage: 18/10/18[d]	LTO
	Tsuruga-2 (PWR)	1 108	1986	34.0	07/05/11	8.8	05/11/15		LTO
KEPCO	Mihama-3 (PWR)	780	1976	44.4	14/05/11	9.1	17/03/15	Second Stage: 26/10/16[e]	LTO
	Ohi-3 (PWR)	1 127	1991	29.1	02/09/13	(4.5)	08/07/13	01/09/17	Restarted 16/03/18
	Ohi-4 (PWR)	1 127	1992	28.0	15/09/13	(4.6)	08/07/13	01/09/17	Restarted 11/05/18
	Takahama-1 (PWR)	780	1974	46.3	10/01/11	9.5	17/03/15	Second Stage: 10/06/16[f]	LTO
	Takahama-2 (PWR)	780	1975	45.4	25/11/11	8.6	17/03/15	Second Stage: 10/06/16[f]	LTO
	Takahama-3 (PWR)	830	1984	36.1	20/02/12	(3.9)	08/07/13	09/10/15	Restarted 9/06/17[g]
	Takahama-4 (PWR)	830	1984	35.7	21/07/11	(5.8)	08/07/13	09/10/15	Restarted 22/05/17
KYUSHU	Genkai-3 (PWR)	1 127	1993	27.0	11/12/10	(7.3)	12/07/13	14/09/17	Restarted 23/03/18
	Genkai-4 (PWR)	1 127	1996	23.6	25/12/11	(6.5)	12/07/13	14/09/17	Restarted 20/06/18
	Sendai-1 (PWR)	846	1983	36.8	10/05/11	(4.3)	08/07/13	27/05/15	Restarted[h] 14/08/15
	Sendai-2 (PWR)	846	1985	35.2	01/09/11	(4.1)	08/07/13	27/05/15	Restarted[h] 15/10/15
SHIKOKU	Ikaka-3 (PWR)	846	1994	26.3	29/04/11	(5.3)	08/07/13	19/04/16	Restarted[i] 15/08/16
TEPCO	Kashiwazaki Kariwa-1 (BWR)	1 067	1985	35.4	06/08/11	8.9			LTO
	Kashiwazaki Kariwa-2 (BWR)	1 067	1990	30.4	05/07/07	13.0			LTO
	Kashiwazaki Kariwa-3 (BWR)	1 067	1992	27.6	16/07/07	13.0			LTO
	Kashiwazaki Kariwa-4 (BWR)	1 067	1993	26.5	16/07/07	13.0			LTO
	Kashiwazaki Kariwa-5 (BWR)	1 067	1989	30.8	25/01/12	8.4			LTO
	Kashiwazaki Kariwa-6 (BWR)	1 315	1996	24.4	26/03/12	8.3	27/09/13[j]	First Stage: 27/12/17	LTO
	Kashiwazaki Kariwa-7 (BWR)	1 315	1996	23.5	23/08/11	8.9	27/09/13	First Stage: 27/12/17	LTO
TOHOKU	Higashi Dori-1 (BWR)	1 067	2005	14.8	06/02/11	9.4	20/06/14		LTO
	Onagawa-2 (BWR)	796	1994	25.5	06/11/10	9.7	27/12/13	First Stage: 26/02/20[k]	LTO
	Onagawa-3 (BWR)	796	2001	19.1	11/03/11	9.3			LTO
Total: 33 Reactors / 31.7 GWe									

Sources: JAIF, NRA, compiled by WNISR, 2020

Notes

BWR = Boiling Water Reactor; PWR = Pressurized Water Reactor; LTO = Long-Term Outage.

a – The shutdown dates are from JAIF, “Current Status of Nuclear Power Plants in Japan”, Japan Atomic Industrial Forum, as of 4 June 2020, Japan Atomic Industrial Forum, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2019/06/jp-npps-operation190606_en.pdf, accessed 4 June 2020.

b – Unless otherwise indicated the application and approval dates are from NRA, “Current circumstances regarding examinations for NPP adherence to new regulations”, Nuclear Regulatory Authority, 15 May 2019; and NRA, “Regarding the progress status of the new regulatory standard compliance examination, (Power reactor relation)”, 1 July 2020 (in Japanese), see https://www.nsr.go.jp/data/000257174.pdf, accessed 28 July 2020. Gray dates refer to the first stage (Permission for change in reactor-installation) or second stage (Construction plan approval) of the procedure. All others indicate final agreement of the 3-step conformity review.

c – Application withdrawn and resubmitted on 26 January 2015.

d – Nuclear Regulatory Authority’s (NRA) Approval for Basic Design (Step 2). In November 2018, NRA also approved lifetime extension to 60 years; see JAIF, “NRA Allows Tokai-2 to Be Operated for Sixty Years, a First for a BWR”, 16 November 2018, see https://www.jaif.or.jp/en/nra-allows-tokai-2-to-be-operated-for-sixty-years-a-first-for-a-bwr/, accessed 28 April 2019.

e – Application for extension of operating period approved by NRA on 16 November 2016.

f – For both Takahama-1 and -2, the first two steps of the conformity review were achieved on 10 June 2016. The NRA also granted KEPCO approval of extension of operation for 20 years on 20 June 2016. For details see NRA, “The NRA approved the extension of operation period of Takahama Power Station Units 1 and 2”, 21 June 2016, see http://www.nsr.go.jp/data/000154256.pdf, accessed 14 July 2017.

g – Takahama-3 had operated briefly between 29 January and 10 March 2016, before it was shut down by court order. The “Shutdown Duration” is calculated until the first restart.

h – Kyushu Electric Power Company was required to finish installing counter-terrorism facilities at the Sendai-1 and -2 reactors by 17 March and 21 May 2020, respectively, but missed the deadline. As a result, Sendai-1 has been shut down since 16 March 2020 and is scheduled for restart on 26 December 2020. While Sendai-2 was shut down on 20 May 2020 after only operating for four months following its maintenance and inspection outage completed in January. It is scheduled for restart on 26 January 2021

i – In December 2019, Ikata-3 was shut down for maintenance and refueling (with restart of operation expected on 27 April 2020). On 17 January 2020, the Hiroshima High Court ruled in favor of a lawsuit brought by local residents within a 50-kilometer radius of the Ikata plant, the effect of which was to extend the outage of the Ikata-3 reactor; see *Asahi Shimbun*, “Residents win appeal to halt Ikata reactor over safety fears”, 17 January 2020, see http://www.asahi.com/ajw/articles/AJ202001170057.html, accessed 15 May 2020.
As of 1 July 2020 the court order remained in place with the likelihood of a further court decision following appeal by Kyushu Electric decision from September 2020.

j – On 16 June 2017, TEPCO re-filed its application with the Nuclear Regulatory Authority (NRA) to confirm compliance with safety requirements for Kashiwazaki Kariwa-6 and -7. The NRA had requested resubmission in February 2017.

k – JAIF, “NRA Approves Changes to Reactor Installation for Onagawa-2 under New Regulatory Standards”, 27 February 2020, see https://www.jaif.or.jp/en/nra-approves-changes-to-reactor-installation-for-onagawa-2-under-new-regulatory-standards/, accessed 20 May 2020.

ANNEX 4 - STATUS OF NUCLEAR POWER IN THE WORLD

Table 24 · Status of Nuclear Power in the World (as of 1 July 2020)

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	1 633		29.8	1	5.9%	(+)	2.2%	(=)
Armenia	1	375		40.5		27.8%	(+)		
Bangladesh	-	-		-	2				
Belarus	-	-		-	2				
Belgium	7	5 920		40.3		47.6%	(+)	14.4%	(+)
Brazil	2	1 884		29.1		2.7%	(=)	1.2%	(=)
Bulgaria	2	2 006		30.8		37.5%	(+)	19.8%	(+)
Canada	19	13 554		37		14.9%	(=)	6.3%	(=)
China	47	45 498	1	8.2	15	4.9%	(=)	2.2%	(=)
Czech Republic	6	3 932		29		35.2%	(=)	15.8%	(=)
Finland	4	2 784		41.3	1	34.7%	(+)	18.6%	(=)
France	56	61 370		35.1	1	70.6%	(-)	36.8%	(=)
Germany	6	8 113		33.5		12.4%	(=)	5.1%	(=)
Hungary	4	1 902		35.0		49.2%	(-)	14.6%	(=)
India	20	5 960	1	23.3/22.6	7	3.2%	(=)	1.2%	(=)
Iran	1	915		7.8		1.8%	(=)	0.5%	(=)
Japan	9	8 706	24	29.4/30.9	1	7.5%	(+)	3.1%	(=)
Mexico	2	1 552		28.4		4.5%	(=)	1.3%	(=)
Netherlands	1	482		47.0		3.2%	(=)	1%	(=)
Pakistan	5	1 318		16.9	2	6.6%	(=)	2.4%	(=)
Romania	2	1 300		18.5		18.5%	(+)	7.3%	(=)
Russia	38	28 437		28.5	3	19.7%	(+)	6.3%	(=)
Slovakia	4	1 814		28.3	2	53.9%	(-)	21%	(=)
Slovenia	1	688		38.7		37%	(+)	18.5%	(=)
South Africa	2	1 860		35.6		6.7%	(+)	2.3%	(=)
South Korea	22	21 216	2	21.1/20.6	4	26.2%	(+)	10.5%	(+)
Spain	7	7 121		35.4		21.4%	(=)	9.1%	(=)
Sweden	7	7 740		35.4		34%	(-)	26.7%	(-)
Switzerland	4	2 960		44.3		35.2%	(=)	18.2%	(-)
Taiwan	4	3 844		37.1		13.4%	(+)	6%	(+)
Turkey	-	-		-	2				
UAE	-	-		-	4				
UK	12	7 343	3	36.4/35.8	1	15.6%	(-)	6.4%	(=)
Ukraine	15	13 107		31.4		53.9%	(=)	21.7%	(=)
USA	95	97 154		39.8	2	19.7%	(=)	8%	(=)
EU27	107	105 182		35.1	4				
EU28					5	25.6%[c]	(=)	10.7%	(=)
World	408	362 506	31	30.6	52	10.3%[c]	(=)	4.3%	(=)

Sources: WNISR, IAEA-PRIS, BP, 2020

a – Including reactors in LTO/Excluding reactors in LTO (when different).

b – From IAEA-PRIS, "Nuclear Share of Electricity Generation in 2019", as of 8 August 2020 – except for Switzerland, see SFOE, "Schweizerische Elektrizitätsstatistik 2019", Swiss Federal Office of Energy, June 2019 (in German/French).

c – From BP, "Statistical Review of World Energy", 2020.

ANNEX 5 - NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION"

Table 25 · Nuclear Reactors in the World "Under Construction" (as of 1 July 2020)

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
ARGENTINA	**25**					
Carem25		25	CAREM (PWR)	08/02/2014	2021[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	**2**	**2 218**				
Belarusian-1		1 109	VVER V-491	06/11/2013	2020[4]	yes
Belarusian-2		1 109	VVER V-491	03/06/2014	2021[5]	yes
CHINA	**15**	**13 842**				
CFR-600		600	FBR	29/12/2017	2023[6]	
Fangchenggang-3		1 000	HPR-1000	24/12/2015	2021[7]	
Fangchenggang-4		1 000	HPR-1000	23/12/2016	2022[8]	
Fuqing-5		1 000	HPR-1000	07/05/2015	2020[9] (completion)	yes
Fuqing-6		1 000	HPR-1000	22/12/2015	2021[10]	yes
Hongyanhe-5		1 000	ACPR-1000	29/03/2015	2021[11]	yes
Hongyanhe-6		1 000	ACPR-1000	24/07/2015	2022[12]	yes
Shidao Bay 1-1[13]		100	HTR-PM	01/12/2012	2021[14]	yes
Shidao Bay 1-2		100	HTR-PM	01/12/2012	2021[15]	yes
Shidao-Bay 2-1[16]		1 400	CAP1400	04/2019[17]	?[18]	
Shidao-Bay 2-2		1 400	CAP1400	11/2019[19]	?[20]	
Taipingling-1		1 116	HPR-1000	26/12/2019[21]	2025[22] (grid connection)	
Tianwan-5		1 000	CNP-1000	27/12/2015	2020[23]	
Tianwan-6		1 000	CPR-1000	07/09/2016	10/2021[24] (commercial operation)	
Zhangzhou-1		1 000	HPR-1000	16/10/2019[25]	2024[26] (grid connection)	
FINLAND	**1**	**1 600**				
Olkiluoto-3		1 600	EPR	12/08/2005	05/2021[27]	yes
FRANCE	**1**	**1 600**				
Flamanville-3		1 600	EPR	03/12/2007	2022[28]	yes

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
INDIA	**7**	**4 824**				
Kakrapar-3		630	PHWR-700	22/11/2010	2020[29]	yes
Kakrapar-4		630	PHWR-700	22/11/2010	September 2021[30] (commissioning)	yes
Kudankulam-3		917	VVER V-412	29/06/2017	3/2023[31] (commercial operation)	
Kudankulam-4		917	VVER V-412	23/10/2017	11/2023[32] (commercial operation)	?
PFBR		470	FBR	23/10/2004	10/2021[33]	yes
Rajasthan-7		630	PHWR	18/07/2011	02/2022[34] (expected completion)	yes
Rajasthan-8		630	PHWR	30/09/2011	03/2023[35] (commercial operation)	yes
IRAN	**1**	**1 196**				
Bushehr-2		1 196	VVER V-446	02/1976[36]	2024	yes
JAPAN	**1**	**1 325**				
Shimane-3		1 325	ABWR	12/10/2007	?[37]	yes
PAKISTAN	**2**	**2 028**				
Kanupp-2		1 014	ACP-1000	20/08/2015	2021[38] (expected operation)	yes
Kanupp-3		1 014	ACP-1000	31/05/2016	2021[39] (expected operation)	
RUSSIA	**3**	**3 115**				
Kursk 2-1		1 115	VVER V-510	29/04/2018	2022[40]	
Kursk 2-2		1 115	VVER V-510	15/04/2019	04/2023[41]	
Leningrad 2-2		1 085	VVER V-491	15/04/2010	2021[42]	yes
SLOVAKIA	**2**	**880**				
Mochovce-3		440	VVER V-213	01/01/1985	2020[43]	yes
Mochovce-4		440	VVER V-213	01/01/1985	2021[44]	yes
SOUTH KOREA	**4**	**5 360**				
Shin-Hanul-1		1 340	APR-1400	10/07/2012	10/2020[45] (commercial operation)	yes
Shin-Hanul-2		1 340	APR-1400	19/06/2013	8/2021[46] (commercial operation)	yes
Shin-Kori-5		1 340	APR-1400	03/04/2017	3/2023[47] (commercial operation)	yes
Shin-Kori-6		1 340	APR-1400	20/09/2018	6/2024[48]	yes
TURKEY	**2**	**2 228**				
Akkuyu-1		1 114	VVER V-491	03/04/2018	2024[49]	yes
Akkuyu-2		1 114	VVER V-491	08/4/2020[50]	2025[51]	
UAE	**4**	**5 380**				
Barakah-1		1 345	APR-1400	19/07/2012	2020[52]	yes
Barakah-2		1 345	APR-1400	30/05/2013	2021[53]	yes
Barakah-3		1 345	APR-1400	24/09/2014	2022[54]	yes
Barakah-4		1 345	APR-1400	30/07/2015	2023[55]	yes
U.K.	**2**	**3 260**				
Hinkley Point C-1	1	1 630	EPR-1750	11/12/2018[56]	2025[57]	
Hinkley Point C-2	1	1 630	EPR-1750	12/12/2019[58]	2026[59]	
USA	**2**	**2 234**				
Vogtle-3		1 117	AP-1000	12/03/2013	11/2021[60]	yes
Vogtle-4		1 117	AP-1000	19/11/2013	11/2022[61]	yes
World	**52**	**53 475**		**1976-2020**	**2020–2026**	**33**

1 - Repeatedly delayed. In 2019, CAREM was rescheduled to begin operating in late 2021 or 2022. The construction, 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 project's timeline. See *NEI*, "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.

2 - 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.

3 - 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.

4 - Further delayed by one year since WNISR2019. Fuel loading started in August 2020, with grid connection expected in fourth quarter of 2020, see *BelTA*, "Fueling of Belarusian nuclear power plant's first reactor in progress", 7 August 2020, see https://eng.belta.by/economics/view/fueling-of-belarusian-nuclear-power-plants-first-reactor-in-progress-132336-2020/, accessed 10 August 2020.

5 - First delay (formally acknowledged). In early 2020, startup of Belarusian-2 was officially delayed to 2021.The reactor is now expected to come online in 2021, a delay of one year since WNISR2019. *BelTA*, "Second reactor of Belarusian nuclear power plant getting flushed, cleansed", 17 June 2020, see https://atom.belta.by/en/belaes_en/view/second-reactor-of-belarusian-nuclear-power-plant-getting-flushed-cleansed-10678/, accessed 16 July 2020.

6 - CFR-600 is not listed as under construction by IAEA-PRIS. Concrete pouring is reported to have taken place in December 2017; commercial operation was then expected 2023. See *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.

7 - No information concerning expected startup date in CGN's announcement of construction start. CGN's Annual Reports for 2016 to 2018 refer to 2022 as "Expected Date of Commencement of Operation" for both units. CGN, "Annual Report 2018", 2019, see http://www3.hkexnews.hk/listedco/listconews/sehk/2019/0408/LTN20190408772.pdf, accessed 9 April 2019. Sources in China suggest that because the two units are the first HPR-1000 to be constructed, grid connection appears impossible before 2020–21 for Unit 3 and 2021–22 for Unit 4, although CGN has pledged to do its utmost to connect its first domestic Generation III reactor to the grid in 2021, at the earliest in November 2021. WNISR2019 advanced the date from 2022 to 2021.

8 - See previous note.

9 - Further delayed since WNISR2019. Completion of the reactor, previously expected in June 2020, is however still expected in 2020. See *NIW*, "China: Economic Case for Nuclear Worsens With Covid-19", 15 May 2020.

10 - Delayed. The completion date announced at construction start was 2020. See *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 26 June 2016.
Grid connection is now expected in 2021. *NEI*, "Outer containment installed at China's Fuqing 6", 30 July 2020, see https://www.neimagazine.com/news/newsouter-containment-installed-at-chinas-fuqing-6-8053007, accessed 4 August 2020.

11 - First delay. In January 2020, CGN announced that operation of of Hongyanhe-5 was delayed to second half of 2021, a delay of one year. CGN Power, "Inside Information - Operation Briefings for the Fourth Quarter of 2019", 6 January 2020, see http://en.cgnp.com.cn/encgnp/c20191226/202001/917f4904f06d4826be1ae98e96780703/files/0627a0191ddb4a07bcfe0b4764a196e4.pdf, accessed 12 January 2020.

12 - First delay. In January 2020, CGN announced that operation of Hongyanhe-6 was delayed to 2022, a delay of six months. CGN Power, "Inside Information - Operation Briefings for the Fourth Quarter of 2019", 6 January 2020.

13 - IAEA-PRIS reports the twin High-Temperature Reactors (HTR-PM) being under construction 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, it turns out that Shidao Bay-1 (also called Shidaowan-1) consists of two 100-MW reactors, and consequently, as of WNISR2020, they are considered separately, i.o.w. as two units under construction (Shidao Bay 1-1 and 1-2). See CNEA, "Key components of second HTR-PM reactor connected", China Nuclear Energy Association, n.d., see http://en.china-nea.cn/site/content/176.html, accessed 10 May 2020.

14 - Further delayed since WNISR2019. Fu Li, "Chinese HTR Program", presented at the IFNEC SMR Webinar Series, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 5 July 2020.

15 - Twin reactor. See previous note.

16 - Provisional names for the two CAP1400 at Rongcheng/Shidaowan. Construction of those reactors was introduced in WNISR stats in 2020 following *NIW* articles (in particular 10 July 2019) and confirmation from sources in China. The two CAP1400 are not listed as under construction neither by WNA (planned, with construction start in 2020) nor IAEA-PRIS. In July 2019, *NIW* classified them as "under construction" on the basis of the NNSA map as of June 2019. See *NIW,* "Why the Secrecy Over Reactor Construction Start?", 12 July 2019.

17 - 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.

18 - No official startup dates at this point. WNISR2020 uses 2025 for modelling purposes.

19 - According to sources in China, first basemat concrete for the second CAP1400 reactor was poured in November 2019. See previous notes.

20 - No official startup dates at this point. WNISR2020 uses 2025 for modelling purposes.

21 - CGN, "Annual Report 2019", CGN Power, April 2020, see http://en.cgnp.com.cn/encgnp/c100882/202004/f3c20533b65c4cf3a41583190c02057c/files/a5bc0c2ac79c425398a2296b2b054005.pdf, accessed 2 April 2020.

22 - WNA, "Nuclear Power in China", July 2020, see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx, accessed 29 July 2020.

23 - Connected to the grid on 8 August 2020. *WNN*, "Tianwan 5 achieves grid connection", 10 August 2020, see https://www.world-nuclear-news.org/Articles/Tianwan-5-achieves-grid-connection, accessed 10 August 2020.

24 - WNISR, "China: Grid Connection for Fuqing-3 and Construction Start on Tianwan-6", 9 September 2016, see https://www.worldnuclearreport.org/China-Grid-Connection-for-Fuqing-3-and-Construction-Start-on-Tianwan-6.html, accessed 22 August 2019.

25 - CNNC, "CNNC's Zhangzhou nuclear plant goes into construction", 23 December 2019, see http://en.cnnc.com.cn/2019-12/23/c_435889.htm, accessed 17 January 2020.

26 - WNA, "Nuclear Power in China", July 2020.

27 - Further delayed. Grid connection is further delayed, at least to May 2021. A further delay of about one year compared to WNISR2019. Roger Fry, "TVO reporte le démarrage d'Olkiluoto 3 (1,6 GW) à mai 2021", *Montel*, 2 July 2020 (in French), see https://www.montelnews.com/fr/story/tvo-reporte-le-dmarrage-dolkiluoto-3-16-gw-%C3%A0-mai-2021/1128407, accessed 12 July 2020. TVO, "TVO - OL3 EPR's schedule work continues", 2 July 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprsscheduleworkcontinues.html, accessed 17 August 2020.

28 - Probably further delayed. Delayed many times from its original planned startup date of 2012. As of July 2019, startup was expected in 2022. No new schedule has been provided but in July 2020, EDF noted that "As regards Flamanville 3, in the context of health crisis, all construction activities have been temporarily interrupted between mid-March and early May, which could result in further delays and additional costs.", see EDF, "2020 Half-Year Results", 30 July 2020, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/2020-half-year-results, accessed 30 July 2020.

29 - Further delayed. First criticality achieved on 22 July 2020. A further delay compared to WNISR2019, when commercial operation was expected in December 2019. NPCIL, "Unit-3 of Kakrapar Atomic Power Project achieves First Criticality", 22 July 2020, see https://www.npcil.nic.in/writereaddata/Orders/202007220324143941331News_22jul2020_01.pdf, accessed 28 July 2020.

30 - Further delayed. Jitendra Singh, "Unstarred Question No. 1602: Commissioning of heavy water reactor at Kakrapar Nuclear Plant", Parliament of India, Rajya Sabha, March 2020.

31 - Jitendra Singh, "Unstarred Question No. 1602: Commissioning of heavy water reactor at Kakrapar Nuclear Plant", Parliament of India, Rajya Sabha, March 2020.

32 - Jitendra Singh, "Unstarred Question No. 1602: Commissioning of heavy water reactor at Kakrapar Nuclear Plant", Parliament of India, Rajya Sabha, March 2020. In 2018, ASE quoted 2024 as "guarantee operation date". See Atomstroyexport, "Kudankulam NPP (India)", Undated, see http://www.atomstroyexport.ru/wps/wcm/connect/ase/eng/about/NPP+Projects/Current/Kudankulam_india/, accessed 9 May 2018. In December 2019, Jitendra Singh also quoted "2023-2024" as "expected completion" date for Kakrapar-4, see Department of Atomic Energy and Government of India, "Lok Sabha - Unstarred Question No.3702 To Be Answered on 11.12.2019—Nuclear Power Plants", 11 December 2019, see http://164.100.24.220/loksabhaquestions/annex/172/AU3702.pdf, accessed 2 January 2020.

33 - Repeatedly delayed. Commissioning still expected in October 2021. Department-related Parliamentary Standing Committee on Science & Technology, Environment, Forests and Climate Change, "Demands for Grants (2020-2021) of the Department of Atomic Energy (Demand No. 03)", Parliament of India, Rajya Sabha Secretariat, March 2020.

34 - Further delayed since WNISR2019. As of March 2020, anticipated date for commissioning is March 2022, a year and a half delay compared to WNISR2019. Jitendra Singh, "Unstarred Question No. 1602: Commissioning of heavy water reactor at Kakrapar Nuclear Plant", Parliament of India, Rajya Sabha, March 2020.

35 - Further delayed since WNISR2019. As of March 2020, anticipated date for commissioning is March 2023, 1.5 year of delay compared to WNISR2019. Jitendra Singh, "Unstarred Question No. 1602: Commissioning of heavy water reactor at Kakrapar Nuclear Plant", Parliament of India, Rajya Sabha, March 2020.

36 - Original construction of Bushehr-2 had started in February 1976, and the reactor remained listed as under construction in PRIS-IAEA "Nuclear Power Reactors in the World" until the 1994 edition. See WNISR, "Iran: Construction Restart of Busheer-2", 14 November 2019, see https://www.worldnuclearreport.org/Iran-Construction-Restart-of-Busheer-2.html.

37 - Construction status unclear. Chugoku "took the first step" toward Shimane-3 startup by asking prefectural and local governments for their consent on applying to the Nuclear Regulation Authority (NRA) for safety screening; see *The Asahi Shimbun*, "Process begins at Shimane nuclear plant to operate new reactor", 22 May 2018. Still no clear date for startup. 2021 is used for modeling purposes.

38 - First delay. Expected start of operation, according to PNRA, was 2020 "PNRA Annual Report 2018", 2019, see https://www.pnra.org/upload/pnrarpt/PNRA%20Report%202018.pdf, accessed 15 May 2019. Kanupp-2 is now expected to come on line in 2021, see *The Nation*, "PAEC nuclear power plants expected to connect to grid by end of 2021", 2 July 2020, see https://nation.com.pk/02-Jul-2020/paec-nuclear-power-plants-expected-to-connect-to-grid-by-end-of-2021, accessed 20 July 2020.

39 - No new information on expected start of operation. See "PNRA Annual Report 2018", 2019 and "PNRA Annual Report 2019", 2020.

40 - WNA, "Nuclear Power in Russia", April 2020, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 23 April 2020.

41 - WNA, “Nuclear Power in Russia”, April 2020.

42 - Delayed. In 2018, TASS agency reported that Russia was ready to postpone commissioning of Leningrad 2-2—then planned for February 2020—by two years. As of 2019, commissioning was expected in 2021. As of May 2020, commissioning is expected in April 2021, see *WNN*, “Leningrad II-2 start-up postponed to April 2021”, 19 May 2020, see https://world-nuclear-news.org/Articles/Leningrad-II-2-start-up-postponed-to-April-2021, accessed 19 May 2020. Fuel loading started in July 2020, see *WNN*, “Fuel loading starts at Leningrad II-2”, 20 July 2020, see https://www.world-nuclear-news.org/Articles/Fuel-loading-starts-at-Leningrad-II-2, accessed 2 August 2020.

43 - Further delayed since WNISR2019. Construction was suspended between March 1993 and June 2009. In the Framework of the Strategic Plan, approved by the extraordinary General Assembly of Slovenské Elektrárne, a.s. (SE) on 28 March 2017, operation of Mochovce-3 was expected by the end of 2018. In May 2019, CEO of SE Branislav Strycek announced that startup would be delayed again to March 2020. As of June 2020, the safety authority announced a further delay, partly due to the pandemic crisis, but no new deadline was provided.
See 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”, 16 June 2020, see https://www.ujd.gov.sk/ujd/www1.nsf/$All/4188834860C1B178C125858B002981AB, accessed 7 August 2020;
and Chris Johnstone, “Six-month commissioning delay for Mochovce-3”, *Power in Europe*, 29 June 2020.

44 - Further delayed since WNISR2019. Construction was suspended between March 1993 and June 2009. In the Framework of the Strategic Plan, approved by the extraordinary General Assembly of Slovenské Elektrárne, a.s. (SE) on 28 March 2017, operation of Mochovce-4 was expected by the end of 2019. As of July 2020, it is still expected in 2021. See previous note.

45 - Further delayed since WNISR2019. In August 2019, KHNP’s webpage dedicated to Shin-Hanul-1 introduced a change in Commercial Operation (October 2020), a delay of one year compared to WNISR2019. However, in this revised schedule, fuel loading was to take place in April 2020, which did not happen as of 1 July 2020. KHNP, “Nuclear Power Construction—Shin-Hanul #1,2”, 1 January 2020, see http://cms.khnp.co.kr/eng/content/547/main.do?mnCd=EN03020303, last accessed 8 August 2020.

46 - Further delayed. In August 2019, KHNP’s webpage dedicated to Shin-Hanul-2 announced a change in Commercial Operation (August 2021) a delay of one year compared to WNISR2019. See previous note.

47 - Delayed. Construction officially started in April 2017, suspended in July to resume in October of the same year. Commercial operation at construction start was October 2021, it is now expected in March 2023, almost 1.5 year of delay. KHNP, “Nuclear Power Construction – Shin-Kori #5,6”, various dates, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, last accessed 8 August 2020.

48 - Delayed. KHNP, “Nuclear Power Construction—Shin-Kori #5,6”, Various dates, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, last accessed 8 August 2020

49 - Delayed. 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. Phil Chaffee, “New Build, Revised 2023 Milestone for Akkuyu”, *NIW*, 29 March 2019.

50 - See *NIW*, 31 July 2020.

51 - Officials have repeatedly indicated the scheduled startup date as 2024, but that seems rather impossible. WNISR2020 uses a 5-year construction period. *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.

52 - Repeatedly delayed. In May 2017, startup of Barakah-1 was first postponed to 2018. In May 2018, the reviewed forecast of its operator, Nawah, after it had “completed a comprehensive operational readiness review to generate an updated schedule for the start-up”, is that “the loading of nuclear fuel assemblies required to commence nuclear operations at Barakah Unit 1 will occur between the end of 2019 and early 2020”. See Nawah, “Next phase of preparations for Barakah Unit 1 Nuclear Operations starts”, 28 May 2018, Press Release, see https://www.nawah.ae/media/press-news/2018/05/26/Next-phase-of-preparations-for-Barakah, accessed 26 July 2019.
In July 2019, FANR announced that “Unit 1 construction is complete and the unit is currently undergoing commissioning and testing, prior to receipt of the Operating License from FANR, which is currently in the final stages of reviewing the Operating License application for the Unit, in preparation for the loading of the first nuclear assemblies”. See FANR, “FANR Certifies ENEC’s First group of UAE National Nuclear Reactor Operators”, 8 July 2019, see https://www.fanr.gov.ae/en/media-centre/news?g=0b7fd437-2044-4346-90ef-76d8eaeb5c59, accessed 8 July 2019.
The reactor was connected to the grid in August 2020, see ENEC, “Barakah Nuclear Energy Plant Unit 1 Successfully Connects to UAE’s Transmission Grid”, 19 August 2020, see https://www.enec.gov.ae/news/latest-news/barakah-nuclear-energy-plant-unit-1-successfully-connects-to-uae-transmission-grid/, accessed 23 August 2020.

53 - Delayed. No new date for Barakah-2. WNA uses 2021, a three-year delay compared to original schedule. See WNA, “Plans For New Reactors Worldwide”, August 2020, see https://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx, accessed 21 August 2020. In July 2020, ENEC announced construction completion of Unit 2. ENEC, “ENEC Completes Construction of Unit 2 of the Barakah Nuclear Energy Plant”, 15 July 2020, see https://www.enec.gov.ae/news/latest-news/enec-completes-construction-of-unit-2-of-the-barakah-nuclear-energy-plant/, accessed 16 July 2020.

54 - Delayed. No new date for Barakah-3 in updated schedule. WNA uses 2022, a three-year delay compared to original schedule. (See previous notes).

55 - Delayed. No new date for Barakah-4 in updated schedule. WNA uses 2023, a three-year delay compared to original schedule. (See previous notes).

56 - See 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.

57 - EDF, "Clarifications on Hinkley Point C project", 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 7 May 2018.

58 - 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.

59 - No official startup date announced.

60 - Delayed. Georgia Power is expressing confidence that it can meet target dates of November 2021 and November 2022 for Units 3 and 4 respectively, announced in 2018. Georgia Power, "Georgia Power Announces Resequencing of Vogtle Units 3 & 4 Planned Activities", 23 June 2020, see https://www.prnewswire.com/news-releases/georgia-power-announces-resequencing-of-vogtle-units-3--4-planned-activities-301081896.html, accessed 17 August 2020. No change since WNISR2019.

61 - Delayed. No change since WNISR2019. (See previous note).

ANNEX 6 - 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 (10^9 watts)
GWe	gigawatt electric
TWh	terawatt hour (10^{12} watt-hours)
Bq	Becquerel
Bq/kg	Becquerel per kg
Bq/L	Becquerel per litre
mSv	millisievert
mSv/h	millisievert per hour
Sv	Sievert
Sv/h	Sievert per hour

ACR	Avoidable Cost Rate
AEOI	Atomic Energy Organization of Iran
AFCN/FANC	*Agence Fédérale de Contrôle Nucléaire/Federaal agentschap voor nucleaire contrôle* — Federal Agency for Nuclear Control (Belgium)
AGR	Advanced Gas-cooled Reactor
AKP	*Adalet ve Kalkınma Partisi* — Justice and Development Party (Turkey)
ALPS	Advanced Liquid Processing System
AMF	*Autorité des Marchés Financiers* — Financial Market Authority (France)
ANAV	*Asociación Nuclear Ascó-Vandellós* — Economic interest grouping formed by Endesa Generación and Iberdrola Generación
APE	*Agence des Participations de l'État* — National Holding Agency (France)
ASE	*AtomStroyExport* — Subsidiary of Rosatom (Russia)
ATMEA	ATMEA reactor Design (Joint Company of AREVA and Mitsubishi Heavy Industries)
AWHR	Advanced Heavy Water Reactor
BfS	*Bundesamt für Strahlenschutz* — Federal Office for Radiation Protection (Germany)
BMU	*Bundesministerium für Umwelt, Naturschutz und Nukleare Sicherheit* Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Germany)
BNEF	Bloomberg New Energy Finance
BOO	Build-Own Operate
BREDL	Blue Ridge Environmental Defense League
BWR	Boiling Water Reactor
CANDU	CANadian Deuterium Uranium (reactor design)
CAPEX	Capital Expenditure
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 — The French Alternative Energies and Atomic Energy Commission ***or*** Central Electricity Authority (India)
CEFR	China Experimental Fast Reactor
CEO	Chief Deputy Officer
CER	Canadian Energy Regulator (former National Energy Board or NEB)

ČEZ	*České Energetické Závody* — State-owned Energy Utility (Czech Republic)
CFE	*Comisión Federal de Electricidad* — Federal Electricity Commission
CGN	China General Nuclear Power Corporation
CLP	Containment Liner Plates
CNEA	*Comisión Nacional de Energía Atómica* — National Atomic Energy Commission (Argentina) ***or*** China Nuclear Energy Association
CNEC	China Nuclear Engineering Group Corporation
CNIC	Citizens Nuclear Information Center (Japan)
CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
CSN	*Consejo de Seguridad Nuclear* — Nuclear Safety Council (Spain)
CVTR	Carolinas-Virginia Tube Reactor (U.S.)
DAE	Department of Atomic Energy (India)
DG	Director General
DOE	Department of Energy (U.S. **or** South Africa)
EDF	*Électricité de France* — Power Utility (France)
EIA	Environmental Impact Assessment **or** Energy Information Administration, also referred to as U.S.EIA (U.S.)
ENEC	Emirates Nuclear Energy Corporation
ENEL	*Ente Nazionale per l'Energia Elettrica* — National Electric Power Corporation (Italy)
ENSI/IFSN	*Eidgenössisches Nuklearsicherheitsinspektorat/Inspection Fédérale de la Sécurité Nucélaire* Swiss Federal Nuclear Safety Inspectorate
ENSREG	European Nuclear Safety Regulators Group
EPH	*Energeticky a Prumyslovy Holding* — Czech-Slovak Energy & Industry Holding Company
EPZ	*Elektriciteits Produktiemaatschappij Zuid-Nederland* — Electricity Production Company South-Netherlands
EU	European Union
EURATOM	Treaty establishing the European Atomic Energy Community
EWN	*Entsorgungswerk für Nuklearanlagen* — State-owned Decommissioning Company (Germany) [former Energiewerke Nord]
FANC/AFCN	*Federaal agentschap voor nucleaire contrôle/Agence Fédérale de Contrôle Nucléaire* — Federal Agency for Nuclear Control (Belgium)
FBI	Federal Bureau of Investigation (U.S.)
FBR	Fast Breeder Reactor
FERC	Federal Energy Regulatory Commission (U.S.)
FL3	Flamanville-3
FY	Financial Year
GCR	Gas-Cooled Reactor
GDA	Generic Design Assessment
GE	General Electric (Company, U.S.)
HDR	*Heißdampfreaktor* — Superheated steam reactor
HPC	Hinkley Point C (U.K.)
HTGR	High-Temperature Gas-cooled Reactor
HTR	High-Temperature Reactor
HTR-PM	High-Temperature gas-cooled Reactor Pebble-bed Module (Demonstration plant, China)
HWGCR	Heavy Water Gas-Cooled Reactor
IAEA	International Atomic Energy Agency
IANS	Indo-Asian News Service
IFNEC	International Framework for Nuclear Energy Cooperation – formerly Global Nuclear Energy Partnership (GNEP)
IMSR	Integral Molten Salt Reactor
INRAG	International Nuclear Risk Assessment Group
IRENA	International Renewable Energy Agency

IRP	Integrated Resource Plan (South Africa)
IRSN	*Institut de Radioprotection et de Sûreté Nucléaire* — Institute for Radiation Protection and Nuclear Safety (France)
JAEC	Japan Atomic Energy Commission or Jordan Atomic Energy Commission
JAIF	Japan Atomic Industrial Forum
JAPC	Japan Atomic Power Company
JCPOA	Joint Comprehensive Plan of Action
JEPX	Japan Electric Power Exchange
JPDR	Japan Power Demonstration Reactor
JSC	Joint Stock Company
KA-CARE	King Abdullah City for Atomic and Renewable Energy (Saudi Arabia)
KAERI	Korea Atomic Energy Research Institute (South Korea)
KEPCO	Korean Electric Power Corporation ***or*** Kansai Electric Power Company (Japan)
KHNP	Korea Hydro & Nuclear Power (South Korea)
KINS	Korea Institute of Nuclear Safety (South Korea)
LCOE	Levelized Cost Of Energy
LDP	Liberal Democratic Party (South Korea ***or*** Japan)
LTE	Long-Term Enclosure
LTO	Long-Term Outage
LTS	Long-Term Shutdown (IAEA definition)
MBS	Mohammed bin Salman (Crown Prince of Saudi Arabia)
METI	Ministry of Economy, Trade and Industry (Japan)
MHLW	Ministry of Health, Labor and Welfare (Japan)
MIT	Massachusetts Institute of Technology (U.S.)
MITECO	*Ministerio para la Transición Ecológica y el Reto Demográfico* — Ministry for Ecological Transition and Demographic Challenge (Spain)
MMR	Micro Modular Reactor
MNRE	Ministry of New and Renewable Energy (India)
MOEA	Ministry of Economic Affairs (Republic of China, Taiwan)
MOFA	Ministry of Foreign Affairs (Japan)
MOPR	Minimum Offer Price Rule
MOTIE	Ministry of Trade, Industry and Energy (South Korea)
MoU	Memorandum of Understanding
MOX	Mixed Oxide fuel
MTES	*Ministère de la Transition Écologique et Solidaire* — Ministry for Ecological and Solidarity Transition (France) [now *Ministère de la Transition Écologique* — Ministry for the Ecological Transition]
MP	Member of Parliament
MZFR	*Mehrzweckforschungsreaktor* – (Germany)
NAO	National Audit Office (U.K.)
NCCR	Nuclear Construction Cost Recovery tariffs
NDRC	National Development and Reform Commission
NDT	Nuclear Decommissioning Trust (U.S.)
NEA	Nuclear Energy Agency (of the OECD) ***or*** National Energy Administration (China)
NEB	National Energy Board (Canada) — now Canada Energy Regulator (CER)
NECP	National Integrated Energy and Climate Plan 2021–2030
NEI	*Nuclear Engineering International* (Publication) ***or*** Nuclear Energy Institute
NEK	Nuklearna Elektrarna Krško
NELA	Nuclear Energy Leadership Act (USA)
NEPA	National Environmental Protection Act (USA)
NGO	Non-Governmental Organization

NIW	*Nuclear Intelligence Weekly* (Publication)
NPCIL	Nuclear Power Corporation of India Ltd
NPP	Nuclear Power Plant
NPPA	Nuclear Power Plants Authority (Egypt)
NPPD	Nuclear Power Production and Development Co. (Iran)
NPS	Nuclear Power Station or National Policy Statement (U.K.)
NRA	Nuclear Regulatory Authority (Japan)
NRDC	Natural Resources Defense Council
NSPC	Nuclear Security and Physical Protection System Cell (Bangladesh Army)
NSSC	Nuclear Safety and Security Commission (South Korea)
NTA	National Tax Agency (Japan)
OECD	Organisation for Economic Co-operation and Development
OKG	Oskarshamns Kraftgrupp AB
OL3	Olkiluoto-3 (Reactor, Finland)
ONR	Office for Nuclear Regulation (U.K.)
OPG	Ontario Power Generation (Canada)
PFBR	Prototype Fast Breeder Reactor
PGE	*Polska Grupa Energetyczna* — State-owned Public Power Company (Poland)
PHWR	Pressurized Heavy Water Reactors
PJM	Pennsylvania-New Jersey-Maryland Interconnection LLC (U.S.)
PLEX	Plant Life Extension
PPA	Power Purchase Agreement
PPE	Programmation Pluriannuelle de l'Énergie — Multi-Annual Energy Plan (France) ***or*** Pre-Project Engineering
PSC	Public Services Commission (Georgia, South Carolina or New York U.S.)
PSOE	*Partido Socialista Obrero Español* – Socialist Party (Spain)
PV	Photovoltaic
Q1	1st Quarter
RAB	Regulated Asset Base
RBMK	*Reaktor Bolshoy Moshchnosti Kanalnyi* — Graphite-Moderated Reactor (Chernobyl Type)
REN21	Renewable Energy Policy Network for the 21st Century
RGGI	Regional Greenhouse Gas Initiative (U.S.)
RSK	*Reaktor-Sicherheitskommission* — Reactor Safety Commission (Germany)
RTE	*Réseau de Transport d'Électricité* — Transmission System Operator (France)
RWE	*Rheinisch-Westfälisches Elektrizitätswerk* — RWE AG — Rhine-Westphalia Power Utility (Germany)
SEC	Securities and Exchange Commission (U.S.)
SES	Swiss Energy Foundation
SFOE	Swiss Federal Office of Energy
SLC	Site License Company
SMART	System-integrated Modular Advanced Reactors
SMR	Small Modular Reactor
SNBC	*Stratégie National Bas-Carbone* – National Low-Carbone Strategy (France)
Sogin	Società Gestione Impianti Nucleari SpA – State-owned Decommissioning Company
SPIC	State Power Investment Corporation
SSM	*Strålsäkerhetsmyndigheten* — Swedish Radiation Safety Authority
STUK	*Säteilyturvakeskus* – Radiation and Nuclear Safety Authority (Finland)
SÚJB	*Státní úřad pro jadernou bezpečnost* — State Office for Nuclear Safety (Czech Republic)
TEG	Technical Expert Group

TEPCO	Tokyo Electric Power Company (Japan)
THTR	*Thorium-Hoch-Temperatur-Reaktor* — Thorium High-Temperature Reactor
TMI	Three Mile Island Nuclear Power Plant (U.S.)
TSO	Technical Support Organization
TVEL	Nuclear fuel cycle Company (Russia)
TVO	*Teollisuuden Voima Oyj* — Nuclear Power Company (Finland)
U.K.	United Kingdom
U.S.	United States
UAE	United Arab Emirates
UAMPS	Utah Associated Municipal Power Systems
ÚJD	*Úrad jadrového dozoru Slovenskej republiky* – Nuclear Regulatory Authority (Slovakia)
UNECE	UN Economic Commission for Europe
USA	United States of America
UVEK/ DETEC	*Eidgenössische Departement für Umwelt, Verkehr, Energie und Kommunikation/ Département fédéral de l'environnement, des transports, de l'énergie et de la communication* — Federal Department of the Environment, Transport, Energy and Communications (Switzerland)
VAK	*Versuchsatomkraftwerk*
VD4	4e Visite Décennale – 4th Decennial Safety Review (ASN, France)
VVER	*Vodo-Vodianoï Energuetitcheski Reaktor* — Russian Pressurized Water Reactor Designs
WNA	World Nuclear Association
WNISR	World Nuclear Industry Status Report
WNN	*World Nuclear News* (Publication of the World Nuclear Association)
ZLN	*Zwischenlager Nord* – Nuclear Waste Storage Facility (Germany)

ANNEX 7
ABOUT THE AUTHORS

Mycle Schneider is an independent international analyst on energy and nuclear policy based in Paris. He is the Convening Lead Author and Publisher of the World Nuclear Industry Status Reports (WNISR). Mycle is a founding board member of the International Energy Advisory Council (IEAC) and serves 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, U.S and the International Nuclear Risk Assessment Group (INRAG). He has provided information and consulting services, amongst others, to the Belgian Energy Minister, the French and German Environment Ministries, the U.S. Agency for International Development, the International Atomic Energy Agency, the European Commission, and the French Institute for Radiation Protection and Nuclear Safety. Schneider has given evidence and held briefings at national Parliaments in 15 countries and at the European Parliament. He has given lectures at over 20 universities and engineering schools around the globe. In 1997, along with Japan's Jinzaburo Takagi, he received the Right Livelihood Award, also known as the "Alternative Nobel Prize".

Antony Froggatt joined Chatham House in 2007 and is a Senior Research Fellow in the Energy, Environment and Resources Department. He studied energy and environmental policy at the University of Westminster and the Science Policy Research Unit at Sussex University and is currently an Associate Member of the Energy Policy Group at Exeter University. For over 20 years he has been involved in the publication of the World Nuclear Industry Status Report. At Chatham House, he specializes on global electricity policy and the public understanding of climate change. He has worked as an independent consultant for two decades with environmental groups, academics and public bodies in Europe and Asia as well as a freelance journalist. His most recent research project is understanding the energy and climate policy implications of Brexit.

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. 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.

Frank N. von Hippel is a Senior Research Physicist and Professor of Public and International Affairs emeritus in Princeton University's Program on Science and Global Security, which he co-founded. He was also a founding co-chair of the International Panel on Fissile Materials (IPFM) and served as Assistant Director for National Security in the White House Office of Science and Technology Policy during 1993–1994. He has worked on nuclear safety and nonproliferation issues since 1974, when he organized the American Physical Society's (APS) Study on Light Water Reactor Safety. He advised the Carter Administration on its decision to end the U.S. plutonium breeder reactor program, the Clinton Administration on its decision to end nuclear testing and President Gorbachev's arms control advisors on ending the Soviet-U.S. nuclear arms race. He has received numerous awards, including the MacArthur Foundation's "genius" fellowship in 1993 and the APS Leo Szilard award for "for his outstanding work and leadership in using physics to illuminate public policy in the areas of nuclear arms control and nonproliferation, nuclear energy, and energy efficiency."

Jungmin Kang is an independent consultant and South Korea's member of the International Panel on Fissile Materials (IPFM). He was chairman of South Korea's Nuclear Safety and Security Commission in 2018. Dr. Kang was a senior research fellow in the Nuclear Program at Natural Resources Defense Council (NRDC) in 2015–2017. Previously, he was a visiting professor at the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, South Korea. He holds a Ph.D. in Nuclear Engineering from Tokyo University in Japan and completed his BS and MS at the Nuclear Engineering Department of South Korea's Seoul National University. Dr. Kang has held previous positions at the Program on Science and Global Security, Princeton University, the Center for International Security and Cooperation (CISAC), Stanford University, and the School of Advanced International Studies (SAIS), Johns Hopkins University, all in the U.S.

Ali Ahmad is a Research Fellow at Harvard Kennedy School's Project on Managing the Atom and International Security Program (ISP). His research interests include energy security and resilience and the political economy of nuclear energy in newcomer markets, with focus on the Middle East. Prior to joining MTA, Ali served as Director of the Energy Policy and Security Program at the American University of Beirut. From 2013 to 2016, Ali was a postdoctoral fellow at Princeton University's Program on Science and Global Security where he worked on informing nuclear diplomacy with Iran. Outside academia, Ali is a senior consultant at the World Bank advising the Energy and Extractive Industries Global Practice. Ali holds a first degree in Physics from the Lebanese University and a PhD in Engineering from Cambridge University.

Tadahiro Katsuta holds a PhD in plasma physics from Hiroshima University (1997). He is currently a Professor at Meiji University, Tokyo, Japan. During 2014–2015 he was a Visiting Fellow in the Program on Science and Global Security (PSGS) at Princeton University, U.S. He is researching Japan's spent fuel management issues. He is also studying the Fukushima Daiichi nuclear power plant accident and following the new regulation standards with a focus on technical and political aspects. He has been appointed by Japan's Nuclear Regulation Authority (NRA) as a member of the study teams on the New Regulatory Requirements for Commercial Nuclear Power Reactors, for Nuclear Fuel Facilities, Research Reactors, and for Nuclear Waste Storage/Disposal Facilities. During 2008–2009, he conducted research on multilateral nuclear fuel cycle systems as a Visiting Fellow at PSGS. During 2006–2008, he carried out research at the University of Tokyo on separated plutonium issues linked to the Rokkasho reprocessing plant. During 1999–2005, he worked as a researcher at the Citizens Nuclear Information Center (CNIC) in Tokyo.

M.V. Ramana is the Simons Chair in Disarmament, Global and Human Security and Director of the Liu Institute for Global Issues at the School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada. During 2020–2021, he will be a Scholar at the Peter Wall Institute for Advanced Studies. 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.

Ben Wealer is a Research Associate at the Workgroup for Economic and Infrastructure Policy (WIP) at Berlin University of Technology (TU Berlin), and guest researcher at DIW Berlin (German Institute for Economic Research). He holds an MSc in Industrial Engineering in the discipline of energy and resource management from TU Berlin. His field of research is nuclear power economics with a focus on organizational models for decommissioning of nuclear power plants and radioactive waste management, economics of nuclear power plant new-build, and the dual-use issues of nuclear power. Wealer is a founding member of a research project on nuclear energy in Germany, Europe, and abroad run jointly by TU Berlin and DIW Berlin and he is a co-author of the first German independent decommissioning monitoring survey.

Agnès Stienne is an artist, cartographer, and independent graphic designer. She has contributed for over 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, including international treatises on armed conflicts, and the damages of wars. She currently leads a research project focusing on agricultural practices, "land grabbing" and other fundamental agriculture and food 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. Over the Summer 2017, the exhibition "Géopoétique des champs", in the framework of the #Ensemble Festival, presented her work at the Musée de la Mode et du Design in Paris. Her assignments include the design of the United Nations "Unosat Global Report on Maritime Piracy: a geospacial analysis 1995-2003", published in 2014.

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.