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THE WORLD NUCLEAR INDUSTRY

STATUS REPORT 2018

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The World Nuclear Industry
Status Report 2018

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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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A VIEW FROM CHINA

by HAN Wenke and ZHOU Jie[1]

The development of the world's nuclear industry currently faces economic, environmental, and safety concerns. A stream of problems must be dealt with, including, among others, the sourcing of funds; the attainability of uranium resources; the processing of nuclear waste; the safety issues within nuclear technology; public opinion and social acceptability; the aging of nuclear facilities and professional staff; the difficulty of ensuring nuclear non-proliferation; and of course competition from renewable energy sources. Past nuclear disasters at Three Mile Island-2 in the United States, Chernobyl in the Soviet Union, and Fukushima in Japan have all undoubtedly contributed to strong currents of anti-nuclear sentiment throughout the world. Caught in between the strong and often vocal conflicts of the pro- and anti-nuclear factions, a confused public may easily lose sight of the truth. The question of how to overcome this binary opposition, and rationalize the discourse concerning the nuclear industry, is no less than a test of human intellect.

The World Nuclear Industry Status Report (WNISR), chiefly edited by Mycle Schneider, provides for us just such an objective and independent report, based on a third-party-perspective which can open the gate to discussions of sustainable development of nuclear energy. This reputable report gives a detailed and thorough summative description of all the significant changes in the world nuclear industry this year, enriched by specific information for individual regions and countries.

Last year we translated the entirety of the WNISR2017 into Chinese to facilitate wider circulation, which proved to have a positive influence and inspired deep reflection within the Chinese readership. Nuclear power has consistently throughout the last 20 years been the most important option to replace coal-fired power generation, no longer plays that role today. However, the WNISR, with detailed and updated data, shows that the number of nuclear reactors under construction in the world has been steadily decreasing for the last five years (including this year), and that the annual increase in power generation by wind and solar sources has by far surpassed that of nuclear energy, and does provide for Chinese readers a new framework in which to view the issue and a chance to rethink the future of nuclear energy.

China now ranks first in the world in terms of the scale of its nuclear-power programs under construction and is also enthusiastically expanding its international collaborative programs through the 'One Belt One Road' initiative. Domestic construction of nuclear power facilities is slowing down, affected by changes of power supply and demand, public pressure on the safety issues, and by the emphasis placed by the government on the rehabilitation of ecosystems. However, both the Chinese government and nuclear industries remain optimistic and confident about the prospects of nuclear energy. At the same time, we do observe, and experience first-hand, the profound changes in the structure of global energy supply and demand, especially the increase and diversification of energy supplying. These changes can be traced back

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to internal developments in the energy industry, to the influence of the changing international political and economic environment, and to the global response to climate change. After the Fukushima nuclear accident, the nuclear energy industry has certainly been the fastest-changing in the field, compared to other types of energy resources. To researchers and practitioners in China's energy industries, as well as to the quotidian public, there is value to be gained from an awareness of the world's newest trends in nuclear power development, and an appreciation of the development plans and programs (both those completed and those long-anticipated) in other countries in real detail. Apart from experiencing and bearing witness to the growth, progress, and worries associated with our own nuclear industry, this can facilitate a critical, rational approach to thinking of the nuclear industry at large, and inspire ideas as to how China's nuclear power can expand further.

In China, due to the slowing growth in demand for electricity, in combination with the rapid development of wind and solar power as well as the 'excessive' installed capacity of coal power, the need for further development of nuclear power has already diminished considerably. The social context of nuclear power-plant construction is also facing big changes; voices opposing nuclear environmental and safety issues have become inevitable 'warnings' to which policy-makers must respond. The result is the cancellation of some nuclear programs in the preparation phase, and delay of those under construction. Of course, a nuclear program can be delayed or end up over-budget for a variety of reasons. But the ever higher demands for nuclear safety and the growing production costs of newer nuclear technology are impediments that policy- and decision-makers cannot overlook.

On the other hand, in recent years the development of China's renewable energies, especially on-grid wind and solar, have been rapid and significant. Their rates of annual increase are continually among the highest in the world, and the cumulative installation capacity is still growing. The annual amount of electricity generated by wind and solar energies is now level with and even higher than that from nuclear energy. However, holistically, the amount of electricity generated by China's non- hydropower renewable energy still makes up only a very small percentage of the entire amount, and the wind and solar power generation will not be able to form a stronger competitive advantage at the present stage. The cost of manufacturing and installing solar and wind power in China is indeed quickly decreasing; in some provinces, the price of planned solar power can be equal to the price of nuclear power, with no need for state subsidies. The WNISR's discussion about the nuclear power vs renewable energy, and Dave Freeman's view in his Foreword to WNISR2017 that "renewable energy is a lower cost and cleaner, safer alternative to fossil fuels than nuclear power," is a window of thought for Chinese readers.

This year, WNISR2018 is set to greet its readers once again, with a report that is as well-researched and timely as it has ever been. For all those who care about the development of the nuclear industry, to read this new report as soon as possible is something well worth looking forward to, and we certainly trust that in China, this topic will continue to garner more attention in the future.

Beijing, 13 July 2018

FOREWORD 2
A VIEW FROM SOUTH AFRICA

by Anton Eberhard[2]

It's that time of year again when those who value unvarnished data, and analyses of global nuclear energy developments, free of industry spin, look forward to the latest annual World Nuclear Industry Status Report (WNISR). The 2018 edition does not disappoint; it reveals fascinating new information and trends, and confirms that, as the world undergoes a fundamental and far-reaching energy transition, nuclear is being left behind.

I have worked in the energy sector for nearly 40 years and I have never seen as rapid innovation and change as in the last five. The relative prices of electricity generation sources have switched, and solar and wind energy are now, in most countries, the cheapest grid-connected sources of energy. And as storage prices plummet, off-grid power solutions are becoming more cost-competitive. The electricity system is becoming more decentralized, with a multitude of smaller, incremental investments by utilities, industries and households, which are becoming producers as well as consumers of power. Networks and mini-grids are increasingly radial, meshed and fractal, and as energy, transport and communications technologies converge, along with the internet of things, machine learning, demand-side management, and block-chain payment systems, energy services will be democratized and controlled to match optimally individual and community needs.

The nuclear industry seems puzzled by these developments and is mostly in denial. As the competitiveness of solar and wind energy become undeniable – renewable energy auctions are transparent with published long-term contracted prices – the nuclear industry shifts the debate away from the costs of nuclear to issues of system reliability and to its role in the transition to a low-carbon economy. In so doing, they discount the huge construction time and cost overruns in generation III and III+ nuclear reactors and the difficulties of financing nuclear, especially in emerging economies. China is possibly an exception, but it still has to demonstrate that it can achieve the same economies in foreign orders.

Unless the nuclear industry, in the next few years, is able to develop commercially available, smaller, factory-assembled, modular reactors, at lower cost, with reliable, passive safety features, which the private sector would be willing to finance, and institutions insure—the prospects of which seem remote—it is hard to see how nuclear has a place in our energy transition 4.0 or the 4th industrial revolution.

Mycle Schneider, Antony Froggatt and their colleagues, in the WNISR 2018 edition, have once again produced a valuable resource for all those who look for data to understand trends in nuclear energy globally, and in specific countries.

As solar and wind grow exponentially, nuclear energy has remained stagnant. There are fewer nuclear reactors in operation today than there were 30 years ago. Nuclear reactors have increased in size, so they produce more electricity, but still less than in 2001. The share of global

2 - Anton Eberhard is Emeritus Professor and Senior Scholar at the University of Cape Town, following 40 years of research, teaching and policy advocacy in energy and sustainable development in Africa.

electricity production decreased from a peak of 17.5 percent in 1996 to 10.3 percent in 2017. This is hardly a growth industry.

It is instructive to note that the construction of new nuclear power plants is mostly driven and backed by states, and not by the private sector. China accounts for a third of nuclear plants under construction. Nuclear is becoming an option for fewer countries, and only those that are prepared to offer significant government support, including sovereign guarantees. It is regrettable that often this support is facilitated by rent-seeking and corruption.

South Africa provides an interesting case study. It has Africa's only nuclear power station, built by the French in the 1980s. Despite numerous recent electricity generation expansion plans over the past decade, which showed nuclear did not feature in least-cost scenarios, the previous administration, under President Zuma, signed an inter-governmental agreement with Russia committing South Africa to invest in 9600MW of nuclear reactors, supplied by Rosatom. This agreement was struck down by the South African High Court and fortunately the new government has made a commitment to a least-cost energy investment path that is also environmentally sustainable.

A further African example illustrates the futility of nuclear power in developing countries. A number of nuclear co-operation agreements have been concluded between nuclear vendors and African countries. But let's remind ourselves that 27 countries in Sub-Saharan Africa have power systems smaller than 500 MW and 14 smaller than 100 MW! Only Nigeria and South Africa have power systems larger than 3000 MW. The impact of a large nuclear power reactor—typically between 1000 MW and 1600 MW—is obviously problematic in many power systems in developing countries.

I am pleased to see a section in this report on interdependencies between civil and military nuclear infrastructures. South Africa developed nuclear weapons on the back of its nuclear electricity generating industry. It argued that it made sense to enrich uranium for its Koeberg nuclear power station, but it used this as a smokescreen to develop technologies which enabled much higher enrichment levels and the construction of nuclear bombs. As Nelson Mandela was released from prison, and South Africa moved from apartheid to democracy, South Africa became the first country in the world to voluntarily destroy all its nuclear weapons. However, we should not forget how the fuel cycle for nuclear electricity generation plants creates risks for nuclear weapons proliferation.

The past few years have seen the bankruptcy of historically important nuclear energy industries: the U.S./Japan's Westinghouse and France's AREVA, which has had to be taken over by another majority-owned state-owned enterprise. There are fewer and fewer nuclear technology vendors. I hope that future WNISR editions will include a chapter that focusses on the remaining nuclear energy vendors and their prospects for expanding investments in nuclear power markets, not just in their own countries, but also abroad.

The nuclear industry has historically been powerful. It is not easy to hold truth to power. I applaud this publication for doing just that.

Cape Town, 5 August 2018

KEY INSIGHTS

China Still Dominates Developments

- Nuclear power generation in the world increased by 1% due to an 18% increase in China.
- Global nuclear power generation excluding China declined for the third year in a row.
- Four reactors started up in 2017 of which three were in China and one in Pakistan (built by a Chinese company).
- Five units started up in the first half of 2018, of which three were in China—including the world's first EPR and AP1000—and two in Russia.
- Five construction starts in the world in 2017, of which a demonstration fast reactor project in China.
- No start of construction of any commercial reactors in China since December 2016.
- The number of units under construction globally declined for the fifth year in a row, from 68 reactors at the end of 2013 to 50 by mid-2018, of which 16 are in China.
- China spent a record US$126 billion on renewables in 2017.

Operational Status and Construction Delays

- The nuclear share of global electricity generation remained roughly stable over the past five years (–0.5 percentage points), with a long-term declining trend, from 17.5 percent in 1996 to 10.3 in 2017.
- Seven years after the Fukushima events, Japan had restarted five units by the end of 2017—generating still only 3.6% of the power in the country in 2017—and nine by mid-2018.
- As of mid-2018, 32 reactors—including 26 in Japan—are in Long-Term Outage (LTO).
- At least 33 of the 50 units under construction are behind schedule, mostly by several years. China is no exception, at least half of 16 units under construction are delayed.
- Of the 33 delayed construction projects, 15 have reported *increased* delays over the past year.
- Only a quarter of the 16 units scheduled for startup in 2017 were actually connected to the grid.
- New-build plans have been cancelled including in Jordan, Malaysia and the U.S. or postponed such as in Argentina, Indonesia, Kazakhstan.

Decommissioning Status Report

- As of mid-2018, 115 units are undergoing decommissioning—70 percent of the 173 permanently shut-down reactors in the world.
- Only 19 units have been fully decommissioned: 13 in the U.S., five in Germany, and one in Japan. Of these, only 10 have been returned to greenfield sites.

Interdependencies Between Civil and Military Infrastructures

- Nuclear weapon states remain the main proponents of nuclear power programs. A first look into the question whether military interests serve as one of the drivers for plant-life extension and new-build.

Renewables Accelerate Take-Over

- Globally, wind power output grew by 17% in 2017, solar by 35%, nuclear by 1%. Non-hydro renewables generate about 1,700 TWh more power than a decade ago, while nuclear produces less.
- Auctions resulted in record low prices for onshore wind (<US$20/MWh) offshore wind (<US$45/MWh) and solar (<US$25/MWh). This compares with the "strike price" for the Hinkley Point C Project in the U.K. (US$120/MWh).
- Nine of the 31 nuclear countries—Brazil, China, Germany, India, Japan, Mexico, Netherlands, Spain and United Kingdom (U.K.)—generated more electricity in 2017 from non-hydro renewables than from nuclear power.

EXECUTIVE SUMMARY AND CONCLUSIONS

The *World Nuclear Industry Status Report 2018* (*WNISR2018*) provides a comprehensive overview of nuclear power plant data, including information on age, operation, production and construction. The WNISR assesses the status of new-build programs in current nuclear countries as well as in potential newcomer countries. WNISR2018 has put particular attention to seven Focus Countries representing about two thirds of the global fleet. The Fukushima Status Report gives an overview of the standing of onsite and offsite issues seven years after the beginning of the catastrophe. The Decommissioning Status Report for the first time provides an overview of the current state of nuclear reactors that have been permanently closed. A new chapter looks into interdependencies between civil and military uses of nuclear infrastructures. The Nuclear Power vs. Renewable Energy chapter provides global comparative data on investment, capacity, and generation from nuclear, wind and solar energy. Finally, as usual, Annex 1 presents a country-by-country overview of the remaining countries operating nuclear power plants.

Reactor Startups and Shutdowns

Startups. At the beginning of the year, 16 reactors were scheduled for startup in 2017, only 3 made it, plus one that was then expected in 2018: three in China, one in Pakistan (built by Chinese companies).

In mid-2017, 19 reactors were scheduled for startup in 2018, of which one was connected to the grid already in late 2017, but as of mid-2018, only a further five reactors were connected to the grid—three in China and two in Russia—and seven had already been officially delayed until at least 2019. The Chinese startups include the world première of grid connection for a Framatome-Siemens designed European Pressurized Water Reactor (EPR) and a Westinghouse AP1000.

Shutdowns. Three reactors were shut down, respectively the oldest unit in Germany (Gundremmingen-B, 33.5 years), South Korea (Kori-1, 40 years) and Sweden (Oskashamn-1, 46 years).

In December 2017, the International Atomic Energy Agency (IAEA) also announced the permanent closure of one additional reactor in Japan, the fast breeder Monju that had not generated any power since 1995. In August 2017, the IAEA also moved the Spanish reactor Garoña, that had not generated power since 2012, to permanent shutdown. WNISR had already registered both units as closed permanently.

Operation and Construction Data[3]

Reactor Operation and Production. There are 31 countries operating nuclear power plants.[4] These countries operate a total of 413 reactors—excluding Long-Term Outages (LTOs)—a significant increase of 10 units, compared to the situation mid-2017, but two less than 30 years ago in 1988 and 25 fewer than the 2002 peak of 438. The increase is partially due to the restart of 6 reactors previously in LTO.[5] The total installed capacity increased over the past year by 3.4 percent to reach 363 GW[6], which is comparable to 2004 and getting close to the peak of 368 GW in 2006. Annual nuclear electricity generation reached 2,500 TWh in 2017—a 1 percent increase over the previous year, but 6 percent yet below the historic peak in 2006. For the third year in a row, a modest global increase of 26 TWh is essentially due to China, where nuclear generation grew by 38 TWh.

WNISR classifies 26 Japanese reactors as being in LTO.[7] Besides the Japanese reactors, 2 units in India, and 1 each in Argentina (Embalse), China (CEFR), France (Paluel-2)8 and Taiwan (Chinshan-1) met the LTO criteria.

As in previous years, in 2017, the "big five" nuclear generating countries—by rank, the United States, France, China, Russia and South Korea—generated 70 percent of all nuclear electricity in the world. Two countries, the U.S. and France, accounted for 47.5 percent of global nuclear production in 2017.

Share in Electricity/Energy Mix. The nuclear share of the world's power generation remained almost stable over the past five years (–0.5% over the period), with 10.3 percent in 2017, with a long-term declining trend from a historic peak of about 17.5 percent in 1996. Nuclear power's share of global commercial primary energy consumption has remained stable since 2014 at around 4.4 percent.

Reactor Age. In the absence of major new-build programs apart from China, the unit-weighted average age of the world operating nuclear reactor fleet continues to rise, and by mid-2018 stood at 30 years. Over 60% of the total, or 254 units, have operated for 31 or more years, including 77 (18.5%) reaching 41 years or more.

Lifetime Projections. If all currently operating reactors were shut down at the end of a 40-year lifetime—with the exception of the 81 that are already operating for more than 40 years—by 2020 the number of operating units would be 12 below the total at the end of 2017, even if all reactors currently under active construction were completed, with the installed capacity declining by 2 GW. In the following decade to 2030, 190 units (168.5 GW) would have to be replaced—three and a half times the number of startups achieved over the past decade.

3 - 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.

4 - Unless otherwise noted, the figures indicated are as of 1 July 2018.

5 - 7 startups + 6 restarts – 2 new LTOs – 1 shutdown = +10 operating units

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

7 - WNISR considers that a unit is in Long-Term Outage (LTO) if it produced zero power in the previous calendar year and in the first half of the current calendar year. This classification is applied retroactively starting on the day the unit is disconnected from the grid. WNISR counts the startup of a reactor from its day of grid connection, and its shutdown from the day of grid disconnection.

8 - After many delays, Paluel-2 was reconnected to the grid on 23 July 2018. See box in France Focus.

Construction. Fifteen countries are currently building nuclear power plants, two more than in mid-2017, as newcomer countries Bangladesh and Turkey started building their first units. As of 1 July 2018, 50 reactors were under construction—18 fewer than in 2013—of which 16 in China. Total capacity under construction is 48.5 GW.

- The current average time since work started at the 50 units under construction is 6.5 years, a slight increase from the average of 6.2 years one year ago.
- All of the construction projects in at least 7 out of 15 countries have experienced delays. At least two thirds (33-36) of all construction projects are delayed.
- Of 33 delayed construction projects, 15 have reported increased *delays* over the past year.
- Two reactors have been listed as "under construction" for more than 30 years, Mochovce-3 and -4 in Slovakia. Four reactors have been listed as "under construction" for a decade or more, the Prototype Fast Breeder Reactor (PFBR) in India, the Olkiluoto-3 reactor project in Finland, Shimane-3 in Japan and the French Flamanville-3 unit.
- The average construction time of the latest 53 units in nine countries that started up since 2008 was 10.1 years with a very large range from 4.1 to 43.5 years, identical to last year's assessment.

Construction Starts & New-Build Issues

Construction Starts. In 2017, construction began on 5 reactors and in the first half of 2018 on two. This compares to 15 construction starts in 2010 and 10 in 2013. Historic analysis shows that construction starts in the world peaked in 1976 at 44. There has been no construction start of any commercial reactor in China since December 2016.

Construction Cancellations. Between 1970 and mid-2018, a total of 94 (12%) of all construction projects were abandoned or suspended in 20 countries at various stages of advancement. The latest were the two AP1000 units at V.C. Summers in the U.S., abandoned in 2017 after spending some US$5 billion on the project.

Program Delays/Cancellation. Four newcomer countries are actually building reactors—Bangladesh, Belarus, Turkey and United Arab Emirates (UAE). The first reactor startup in UAE—which was reported on-time and on-budget as recently as late 2016 for startup in 2017—is at least three years behind schedule. The first unit in Belarus is about one year delayed, after the reactor pressure vessel was dropped and had to be replaced. The projects in Bangladesh and Turkey only started a few months ago.

New-build plans have been cancelled including in Jordan, Malaysia and the U.S., or postponed incl. in Argentina, Indonesia and Kazakhstan, Other projects ran into serious other problems, for example, Japan's Itochu pulled out of the Turkish Sinop project and South Korea's Electric Power Company KEPCO was stripped of its preferred bidder status, leaving the Moorside project in the U.K. without an investor.

Focus Countries - Overall Shrinking Role of Nuclear

The following seven Focus Countries, covered in depth in this report, represent about two thirds of the global reactor fleet (63 percent of the units and 70 percent of the installed capacity) and six of the world's nine largest nuclear power producers.

China. Nuclear power generation grew by 18 percent in 2017 and contributed 3.9 percent, up from 3.6 percent, of all electricity generated in China.

France. Nuclear plants provided 71.6 percent of the country's electricity, the lowest share since 1988. This is a decline for the fourth year in a row and 7 percentage points below the peak year of 2005 (78.5 percent). France's load factor at 67.7 percent was the fifth lowest in the world.

Germany. Germany's remaining eight nuclear reactors generated 72.2 TWh net in 2017, a 10 percent drop over the previous year and about half of their record year 2001. They provided 11.6 percent of Germany's electricity generation, which is little more than one third of the historic maximum two decades ago (30.8 percent in 1997).

Japan. Nuclear plants provided only 3.6 percent of the electricity in Japan in 2017, ten times less than in 1998. As of mid-2018, nine reactors had restarted and 26 remained in LTO.

South Korea. Nuclear power output dropped 8.6 percent in 2017, supplying 27.1 percent of the country's electricity, little more than half of the maximum 30 years ago (53.3 percent in 1987).

United Kingdom. Nuclear generation decreased by 1.1 percent in 2017 and provided 19.3 percent of the power in the country, down from the maximum of 26.9 in 1997.

United States. Nuclear generation remained stable, and its share in the power mix remained 2.5 percentage point below the record level of 22.5 percent in 1995. State subsidies in the form of Zero Emission Credits (ZEC) have been granted to eight uneconomic nuclear plants to avoid their "early closure". However, a total of 35 units are reported to be uncompetitive (in addition to 6 units already slated for closure).

Fukushima Status Report

Over seven 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 (also referred to as 3/11 throughout the report) and subsequent events.

Onsite Challenges. In September 2017, the Japanese government revised the medium- and long-term roadmap for the decommissioning of the Fukushima Daiichi site. Key components of which are:

- Spent Fuel Removal from the pools of units 1–3 has been delayed for between one and three years. New target dates for the start of the operation are mid-Financial Year (FY) 2018 for unit 3, and "around FY 2023" for units 1 and 2.
- Fuel Debris Removal is still scheduled to begin in 2021 but the determination of the retrieval method has been delayed by one year to FY 2019. On 19 January 2018, fuel debris was identified through visual inspection by remote-controlled camera of the containment vessel of unit 2.

- **Contaminated Water Management.** Large quantities of water—about 3 cubic meters per hour (m3/h) per reactor—are still continuously being injected to cool the fuel debris. The 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 140 m3/day. An equivalent amount of water is decontaminated, although it contains still very high levels of tritium (over 500,000 Bq/l), and stored in large tanks. The storage capacity onsite has been increased to 1.1 million m3 and will be enlarged to 1.4 million m3 by 2020. A frozen soil wall that was designed to further reduce the influx of water was commissioned in 2016. Its effectiveness is limited, as water still enters the basements.

Worker Exposure. 8,000 workers—almost 9 out of 10 are Tokyo Electric Power Company (TEPCO) subcontractors—are involved in decommissioning work. The average doses to subcontractors are more than twice as high as for TEPCO workers. In December 2017, another worker's leukemia—the third case—was recognized as an occupational disease caused by the Fukushima accident. A fourth case, that was recognized, involved thyroid cancer.

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.

- **Evacuees**. According to government figures, the number of evacuees from Fukushima Prefecture as of February 2018 was about 49,500 (vs. 164,000 at the peak in June 2013). The government has lifted restriction orders for five impacted municipalities. However, according to a survey by the Reconstruction Agency, only 3–29% of the people returned, and 15–50% of the people already decided not to return to their homes (or what is left of them). Many remain undecided. In November 2017, the United Nations Human Rights Council (UNHRC) voiced concern about the Japanese government's countermeasures for the evacuees.
- **Health Issues**. Officially, as of the end of December 2017, a total of 197 people have been diagnosed with a malignant tumor or suspected of having a malignant tumor and 161 people underwent surgery. While the cause-effect relationship between Fukushima-related radiation exposure and illnesses has not been established, questions have been raised about the examination procedure itself and the processing of information.
- **Food Contamination**. The highest level of contamination with 11,000 Bq/kg of Cesium (the limit is 100 Bq/kg) was found in wild-boar meat in December 2017. In total, 200 samples out of a total of 300,000 exceeded the limit.
- **Decontamination**. Decontamination activities inside and outside the evacuation area in locations have already generated 16.5 million m3 of contaminated soil. Outside Fukushima Prefecture, contaminated soil is stored in more than 28,000 places (333,000 m^3 in total). The Japanese Government claims that, by March 2018 in Fukushima Prefecture and other affected prefectures decontamination work had been completed where contamination was high (except for the difficult-to-return zones).

Cost of the Accidents. The Japanese Government has not provided a comprehensive estimate for the total cost of the accidents. However, according to the Ministry of Environment, up to FY2017, US$26.6 billion had been allocated to decontamination. TEPCO estimates that

an additional US$6.4 billion will be needed for further decontamination from FY2018-20. According to the latest estimate, TEPCO was expected to borrow about US$119 billion, from the Government for Fukushima related expenditures.

Decommissioning Status Report

The defueling, deconstruction, and dismantling—summarized by the term decommissioning—are the final steps in the lifetime of a nuclear power plant. These processes are technically complex and pose major challenges in terms of the long-term planning, execution and financing. As an increasing number of nuclear facilities either reaches the end of their operational lifetimes or are shut down permanently due to deteriorating economic conditions, the challenges of reactor decommissioning are coming to the fore.

- As of mid-2018, 115 units are undergoing decommissioning—70 percent of the 173 permanently shut-down reactors in the world.
- Only 19 units have been fully decommissioned: 13 in the U.S., five in Germany, and one in Japan. Of these, only 10 have been returned to greenfield sites.

Interdependencies Between Civil and Military Nuclear Infrastructures

Nuclear weapon states remain the main proponents of nuclear power programs. WNISR2018 offers a first look into the question whether military interests serve as one of the drivers for plant-life extension and new-build in some countries.

Why is it that nuclear power is proving surprisingly resistant in particular places around the world, to dramatically changing global energy market conditions and structures for electricity supply? Against a backdrop of decline in the worldwide nuclear industry as a whole, plans for plant life-extension and nuclear new-build remain major areas of investment in a few specific countries. Intense attachments persist to projects like Hinkley Point C in the U.K., despite costs multiplying fivefold over original estimates, a series of still-unresolved technical difficulties and demands for escalating government financial concessions and guarantees.

Evidence is beginning to emerge in a number of leading military nuclear states for additional significant industrial interdependencies around capabilities for sustaining naval nuclear propulsion programs. As civil nuclear power declines in the U.S., a series of recent reports have emphasized the importance for the 'nuclear navy' of a continued national nuclear engineering base supported by policies to sustain the civil nuclear sector. The U.K. Nuclear Industry Council's "Nuclear Sector Deal" states that "the sector is committed to increasing the opportunities for transferability between civil and defense industries and generally increasing mobility to ensure resources are positioned at required locations" and that 18 percent of projected skills gaps can be met by "transferability and mobility". In several countries, it may be that military drivers play a significant role in the persistence of what is otherwise increasingly recognized to be the growing obsolescence of nuclear power as a low-carbon electricity generating technology.

Nuclear Power vs. Renewable Energy Deployment

Global support for a renewable led energy transition is high. The "largest ever study" of attitudes on the green transition carried out in 14 countries found that 82 percent of those surveyed think that it is important to create a world that is fully powered by renewable energy, with the highest national share seen in China, with 93 percent support, and the lowest in Japan, 73 percent.

Investment. Global reported investment for the construction of the four commercial nuclear reactor projects (excluding the demonstration CFR-600 in China) started in 2017 is nearly US$16 billion for about 4 GW. This compares to US$280 billion renewable energy investment, including over US$100 billion in wind power and US$160 billion in solar photovoltaics (PV). China alone invested US$126 billion, over 40 times as much as in 2004. Mexico and Sweden enter the Top-Ten investors for the first time. A significant boost to renewables investment was also given in Australia (x 1.6) and Mexico (x 9). Global investment decisions on new commercial nuclear power plants of about US$16 billion remain a factor of 8 below the investments in renewables in China alone.

Installed Capacity. In 2017, the 157 GW of renewables added to the world's power grids, up from 143 GW added the previous year, represent the largest increase ever. The increase accounted for more than 61 percent of net additions to global power generating capacity. Wind added 52 GW and solar PV a record 97 GW. These numbers compare to a 3.3 GW increase for nuclear power.

Electricity Generation. Nine of the 31 nuclear countries, Brazil, China, Germany, India, Japan, Mexico, Netherlands, Spain and U.K.—a list that includes three of the world's four largest economies—generated more electricity in 2017 from non-hydro renewables than from nuclear power.

In 2017, annual growth for global generation from solar was over 35 percent, for wind power over 17 percent, and for nuclear power 1 percent, exclusively due to China.

Compared to 1997, when the Kyoto Protocol on climate change was signed, in 2017 an additional 1,100 TWh of wind power was produced globally and 442 TWh of solar PV electricity, compared to nuclear's additional 239 TWh.

In China, as in the previous five years, in 2017, electricity production from wind alone (286 TWh), by far exceeded that from nuclear (233 TWh). The same phenomenon is seen in India, where wind power (53 TWh) outpaced nuclear—stagnating at 35 TWh—for the second year in a row.

The figures for the European Union illustrate the rapid decline of the role of nuclear. Compared to 1997, 20 years later, in 2017, wind produced an additional 355 TWh and solar 120 TWh, while nuclear power generation *declined* by 91 TWh.

INTRODUCTION

Heat. The impact of climate change is becoming clearer. The combined data sets from the U.S. National Oceanic and Atmospheric Administrations (NOAA) and the National Aeronautics and Space Administration (NASA) have shown that the five warmest years in the global record have all come in the 2010s.[9] Furthermore, 2017 was the third hottest on record and there are indications that 2018, despite a cool start to the year, maybe even warmer. These all indicate what the future on earth will almost certainly look like.

Water. The food system is the most sensitive to lack of water. As of early August 2018, it is already clear that the draught will severely impact harvests in many parts of the world.

Heat, water and nuclear power. Thermal power plants need vast amounts of cooling water. It is estimated that in France 51 percent of freshwater takeout or about 10 percent of precipitation is absorbed in thermal power plants, with roughly three-quarters of its electricity generated by nuclear power over the years. No other electricity generating source needs more water than atomic fission energy. David Lochbaum, Director of the Nuclear Safety Project at the Union of the Concerned Scientists (UCS), who has produced a fact sheet on "Nuclear Power and Water"[10], stated: "We'll have to solve global warming if we want to keep using nuclear power".[11]

The European Pressurized Water Reactor (EPR) under construction at Flamanville on the coast of Normandy will have its own desalination plant to cope with freshwater needs. Four in-land reactor sites along French rivers with no cooling towers—Bugey (2 units), Fessenheim (2 units), St. Alban (2 units), Tricastin (4 units)—take out about 70 percent of all thermal power plant cooling water in the country. The two oldest French reactors at Fessenheim alone take up about 18 percent of all 17 billion cubic meters of France's annual freshwater takeouts.[12] While these sites consume a large portion of the nation's surface freshwater, they return about 90 percent back to the environment, but significantly heated up.

And that is a problem. In order to make sure reactors can be appropriately cooled, the uptake water temperature is limited for safety reasons, and to avoid excessive heating of the rivers, the operating licenses impose limits to downstream water temperatures. Consequently, as of 1 August 2018, operators in several countries, including Finland, France, Germany, Sweden and Switzerland, had put operational restrictions on some of their nuclear power plants. While in most cases, regulations required to lower the output of the reactors by 10 percent or so, some reactors were shut down, including at least four reactors in France, to deal with the problem.

For now, the heat wave is only a secondary problem for the industry. The malaise about the uncertain future of the industry remains deep and disconcerting.

9 - Climate Central, "The 10 Hottest Global Years on Record", 18 January 2018, see http://www.climatecentral.org/gallery/graphics/the-10-hottest-global-years-on-record, accessed 15 August 2018.

10 - UCS, "Nuclear Power and Water—Quick Facts on Nuclear Power Generation and Water Use", December 2011, Union of Concerned Scientists, see https://www.ucsusa.org/sites/default/files/legacy/assets/documents/nuclear_power/fact-sheet-water-use.pdf, accessed 2 August 2018.

11 - Kari Lydersen, "Amid climate concerns, nuclear plants feel the heat of warming water", *Energy News Network*, 9 September 2016, see https://energynews.us/2016/09/09/midwest/nuclear-plants-feel-the-heat-of-warming-water/, accessed 1 August 2018.

12 - CGDD, "Les prélèvements d'eau par usage et par ressource", Commissariat Général au Développement Durable, French Ministry for the Ecological and Inclusive Transition, 21 June 2017, (in French), see http://www.statistiques.developpement-durable.gouv.fr/lessentiel/ar/234/1108/prelevements-deau-usage-ressource.html, accessed 1 August 2018.

While China proudly presents the competence of its construction industry with the completion of the first Generation-III reactors, designed by western companies Framatome-Siemens and Westinghouse, questions are now being asked about the pace at which the country will continue to expand its nuclear program. No new commercial reactor construction was launched in China since December 2016 (see China Focus). The Foreword by HAN Wenke and ZHOU Jie very well describes the ongoing societal questionings over energy policy options and the role of nuclear power in China (see Foreword Han and Zhou).

In France, the sub-standard pressure vessel of the Flamanville EPR was declared fit to operate by the safety authority, but the vessel head will have to be replaced after only six years of operation. While the startup was delayed again by several months after numerous faulty welds were identified in the main steam supply system. This was the second "deviation" on the same system that builder Électricité de France (EDF) had to report to the regulator within a month. After the technical bankruptcy, subsequent government bailout, breakup and name-change of AREVA to Orano, the new company renews with the same old pattern and lost money again in 2017 (see France Focus).

In Japan, the utilities managed to increase the number of operating reactors to nine. But this remains a very limited success with the plants contributing just 3.6 percent of the national electricity generation and 26 reactors remaining in Long-Term Outage (LTO). Local populations and the general public remain overwhelmingly opposed to the restart of reactors (see Japan Focus). The attempts of the Japanese government to declare certain Fukushima evacuation zones as "decontaminated" and suitable for return did not convince many evacuees (see Fukushima Status Report).

> *"The nuclear industry has created a product so expensive that no one can afford to buy it."*

In the U.K., the Hinkley Point C project is underway but strangely still not officially under construction (see box in United Kingdom Focus). The latest news on new-build in the U.K. is that Toshiba—former owner of bankrupt Westinghouse—has stripped Korea Electric Power Company (KEPCO) of the preferred bidder status to acquire 100 percent of the company NuGen set up to build a nuclear power plant at the Moorside site in Cumbria.[13] KEPCO had been seen as the most promising candidate for the takeover, after other potent potential investors like the French Engie or Spanish Iberdrola left. Toshiba got severely burnt in the Westinghouse bankruptcy and will not build any reactors any more. Prof. John Loughhead, Chief Scientist at the Business, Energy and Industrial Strategy Ministry (BEIS), stated at a conference at the U.K. Royal Society on "Decarbonising U.K. energy" in October 2017: "There are clear issues with nuclear technology at present. The nuclear industry has created a product so expensive that no one can afford to buy it."[14]

In the U.S., many reactors remain threatened with shutdown long before their licenses expire because they cannot compete in the market. The nuclear industry and its supporters are now focusing their efforts on developing innovative subsidizing schemes, in particular at the state level, to help avoiding "early closures" of uneconomic reactors. This report provides a detailed

13 -*WNN*, "Kepco loses preferred bidder status for NuGen", *World Nuclear News*, 1 August 2018, see http://www.world-nuclear-news.org/Articles/Kepco-loses-preferred-bidder-status-for-NuGen, accessed 2 August 2018.

14 -David Lowry, personal communication, 4 October 2017.

state-by-state assessment of the more or less successful support mechanism that are put into place. *Science Daily* titles a research paper[15]: "The vanishing nuclear industry", asking: "Could nuclear power make a significant contribution to decarbonizing the U.S. energy system over the next three or four decades?", only to provide the answer: "Probably not." In May 2018, William Von Hoene, Senior Vice President and Chief Strategy Officer with Exelon, the largest nuclear operator in the U.S., stated: "I don't think we're building any more nuclear plants in the United States. I don't think it's ever going to happen... They are too expensive to construct, relative to the world in which we now live."[16] A recent paper published by the *Proceedings of the National Academy of Sciences* concluded that "because of their great cost and complexity, it appears most unlikely that any new large plants will be built over the next several decades".[17] The recent revelation by the *Wall Street Journal* (WSJ) is therefore barely surprising: "A major donor to President Trump agreed to pay US$10 million to the president's then-personal attorney if he successfully helped obtain funding for a nuclear-power project, including a $5 billion loan from the U.S. government..."[18]

> *"...it appears most unlikely that any new large plants will be built over the next several decades."*

Nuclear new-build is simply not competitive under ordinary market economy rules anywhere. Furthermore, as in the U.S., economic conditions continue to press owners of operating reactors around the world, leading to an increasing number of units being closed earlier than anticipated. WNISR tracks this situation in the individual country sections. The new WNISR's Decommissioning Status Report attempts for the first time to provide an overview of the situation of decommissioning of the 173 reactors that have been closed globally so far.

Considering the rapidly decreasing attractiveness of nuclear new-build in view of potent competitors, especially from the renewable industries, the "odd persistence" of nuclear power raises questions about motivations and interests. One of the possible, under evaluated drivers is the phenomenon of Interdependencies Between Civil and Military Nuclear Infrastructures (see respective chapter). A major stumbling block for the full understanding of the issue remains the exceptional level of secrecy surrounding essential facts and figures.

Finally, maybe the largest barrier to nuclear power development or its mere survival is still the time factor. The German electrical and electronics giant Siemens has just raised the stakes to an unprecedented level. In June 2018, Siemens connected 14.4 GW of turnkey natural gas combined cycle power capacity to the grid in Egypt, 27.5 months aft construction start, three years after contract signature, boosting the national electricity generating capacity by 45 percent. An intermediate step of 4.8 GW, the first of the three giant plants, started up after only 18 months. With over 60 percent efficiency, these combined-cycle gas plants are almost

15 - College of Engineering, Carnegie Mellon University, "The vanishing nuclear industry", published in *Science Daily*, 2 July 2018, see https://www.sciencedaily.com/releases/2018/07/180702154736.htm, accessed 7 July 2018.

16 - With 23 operational reactors, Exelon is the US' largest nuclear operator. Steven Dolley, "No new nuclear units will be built in US due to high cost: Exelon official", *S&P Global*, Platts, 18 April 2018, see https://www.platts.com/latest-news/electric-power/washington/no-new-nuclear-units-will-be-built-in-us-due-26938511, accessed 22 May 2018.

17 - M. Granger Morgan et al., «US nuclear power: The vanishing low-carbon wedge», *PNAS, 2 July 2018, see* http://www.pnas.org/content/early/2018/06/26/1804655115, accessed 17 August 2018.

18 - *WSJ*, "Top Trump Donor Agreed to Pay Michael Cohen $10 Million for Nuclear Project Push", 2 August 2018, see https://www.wsj.com/articles/top-trump-donor-agreed-to-pay-michael-cohen-10-million-for-nuclear-project-push-sources-say-1533245330, accessed 3 August 2018.

twice as efficient as nuclear reactors. The next step is the implementation of up to 600 wind turbines with a total capacity of up to 2 GW, part of the goal of 7.2 GW wind power capacity by 2020.[19]

This is a new benchmark to compare with all of the 14 nuclear reactors started up in the world in 2016 and 2017 with a total capacity of 13 GW and an average construction time of over nine years —and still 6.4 years when excluding the record holder Watts-Bar-2 and its 43.5 building years.

The Nuclear Power vs. Renewable Energy chapter documents not only the continuous rapid expansion of wind and solar, but also the spectacularly low, guaranteed price-levels in electricity auctions around the world.

19 - Siemens, "Completion of world's largest combined cycle power plants in record time", 24 July 2018, see https://www.siemens.com/press/en/feature/2015/corporate/2015-06-egypt.php?content[]=Corp&content[]=WP&content[]=PG&content[]=SFS, accessed 2 August 2018.

GENERAL OVERVIEW WORLDWIDE

THE ROLE OF NUCLEAR POWER

As of the middle of 2018, 31 countries were operating nuclear power reactors. That number has remained stable since Iran started up its first reactor in 2011.

The world nuclear fleet generated 2,503 net terawatt-hours (TWh or billion kilowatt-hours) of electricity in 2017[20], a one percent increase, but still less than in 2001 and 4 percent below the historic peak in 2006 (see Figure 1). Without China—which increased its nuclear output by 35 TWh (+18 percent), more than the worldwide increase of 26 TWh—global nuclear power generation would have slightly decreased again in 2017. This is the third year in a row that China alone avoided a global decrease. In fact, in the past decade, only three years would have seen a global increase without China, 2010, 2013 and 2014, the year before the Fukushima disaster began, and the two years after the 284 TWh (11 percent) production slump in 2011-2012.

Nuclear energy's share of global commercial gross electricity generation remained relatively stable over the past five years (–0.5 percentage points over the period), after dropping below 11 percent in 2012, for the first time in over three decades. The nuclear share in power production declined slowly but steadily from a peak of 17.5 percent in 1996 to 10.3 percent in 2017. Nuclear's contribution to commercial primary energy remained rather stable at 4.4 percent. It has been at this level since 2014 and constitutes a 30-year low.[21]

In 2017, nuclear generation increased in 13 countries, declined in 11, and remained stable in seven.[22] Five countries (China, Hungary, Iran, Pakistan, Russia) achieved their greatest ever nuclear production in 2017.

Some remarkable changes between 2016 and 2017 (see country-specific sections for details):

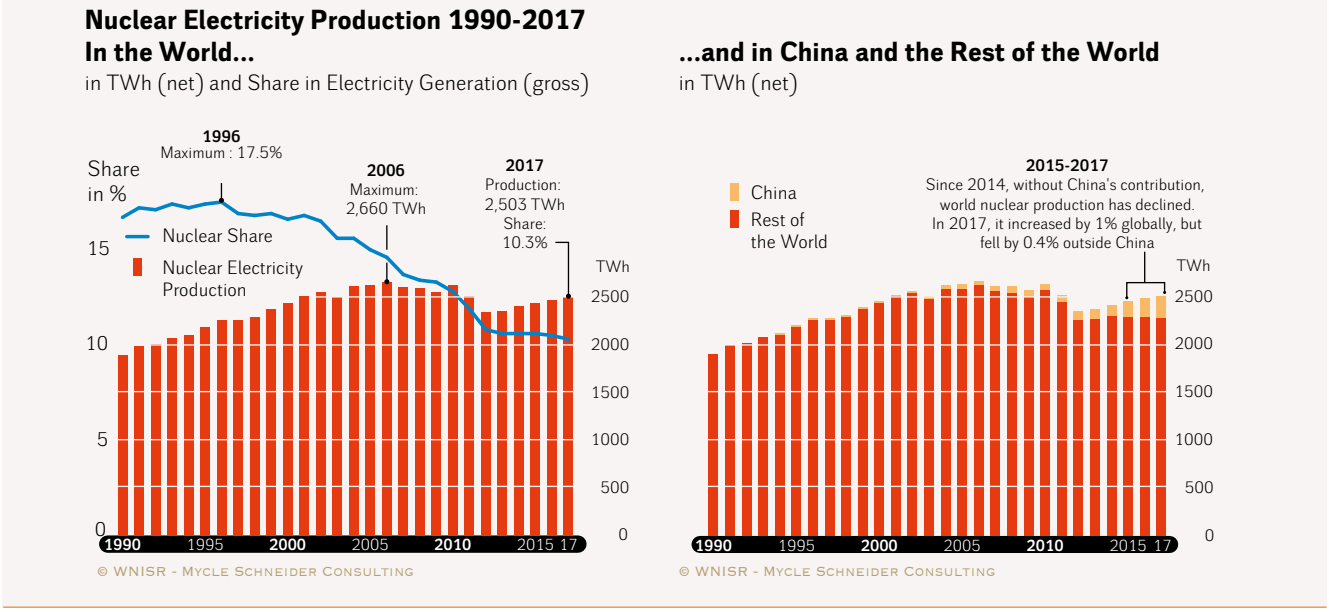
- Argentina's output dropped by over 25 percent, due to the combination of long-term outage for one unit and a low load factor for another.
- China's generation increased by almost 18 percent, ramping up generation from new reactors.
- Japan increased generation after restarting two reactors in 2017 and bringing the total to five by the end of the year (plus four more in 2018). However, nuclear generation still remains modest with less than 12 TWh, hardly more than Mexico or Romania, with two units each.
- Pakistan increased production by a remarkable 49 percent.
- Switzerland's output plunged by over 29 percent.

20 - 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 http://pris.iaea.org/public/. Production figures are net of the plant's own consumption unless otherwise noted.

21 - BP, "Statistical Review of World Energy 2017—67th Edition", June 2018, see https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf, accessed 28 July 2018.

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

Figure 1 | Nuclear Electricity Generation in the World... and China[23]



Sources: WNISR, with BP, IAEA-PRIS, 2018

As in previous years, in 2017, the "big five" nuclear generating countries—by rank, the United States, 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. Two countries, the U.S. and France, accounted for 47.5 percent of global nuclear production in 2017.

Seven countries' nuclear power generation peaked in the 1990s, among them Belgium, Canada, Japan, and the U.K. A further eleven countries' nuclear generation peaked between 2001 and 2010 including France, Germany, Spain, and Sweden. Fourteen countries generated their maximum amount of nuclear power in the past seven years, five of which peaked in 2017.

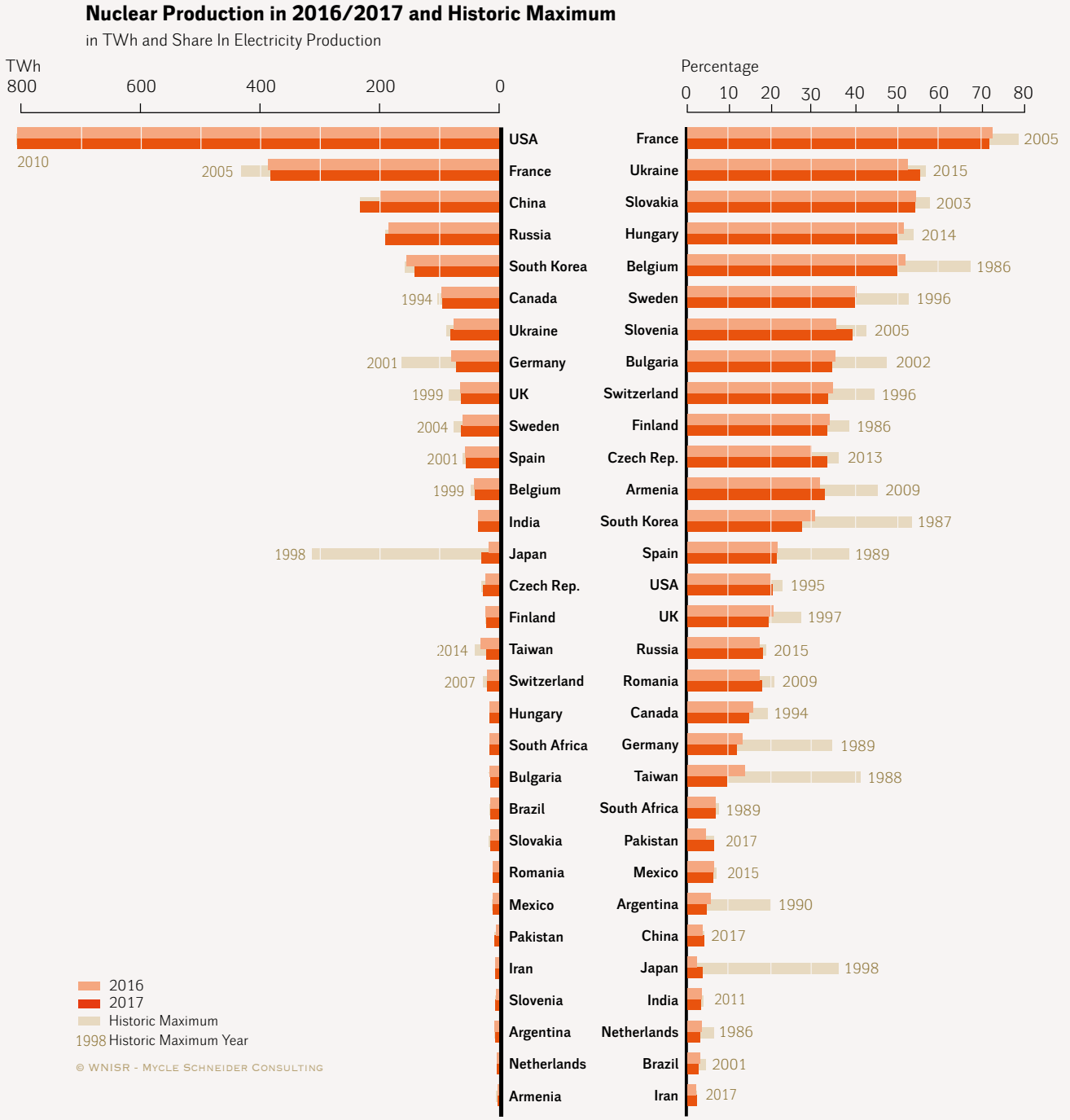
In many cases, even where nuclear power generation increased, the development is not keeping pace with overall increases in electricity production, leading to a nuclear share below the respective historic maximum (see Figure 2, right side). It is therefore remarkable that, in 2017, there were 19 countries that maintained their nuclear share at a constant level (change of less than 1 percentage-point); six countries increased and six decreased their nuclear shares.

There were three exceptions in 2017, where countries peaked their respective nuclear share in power generation:

- Starting up three new reactors throughout the year, augmenting production by 18 percent, China increased the 2016 maximum of 3.6 percent, to reach a new record 3.9 percent nuclear share.

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

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



Sources: IAEA-PRIS, 2018

- Iran's only commercial reactor started up in 2011 after 33 years of construction but it took another five years to reach a reasonable grid-connection time and load factor in 2016. Increasing production by 7.6 percent, the nuclear share increased again slightly from 2.1 percent to 2.2 percent in 2017.
- Pakistan has been increasing production of existing units and started up a new one, which led the nuclear to jump from 4.4 percent to 6.2 percent.

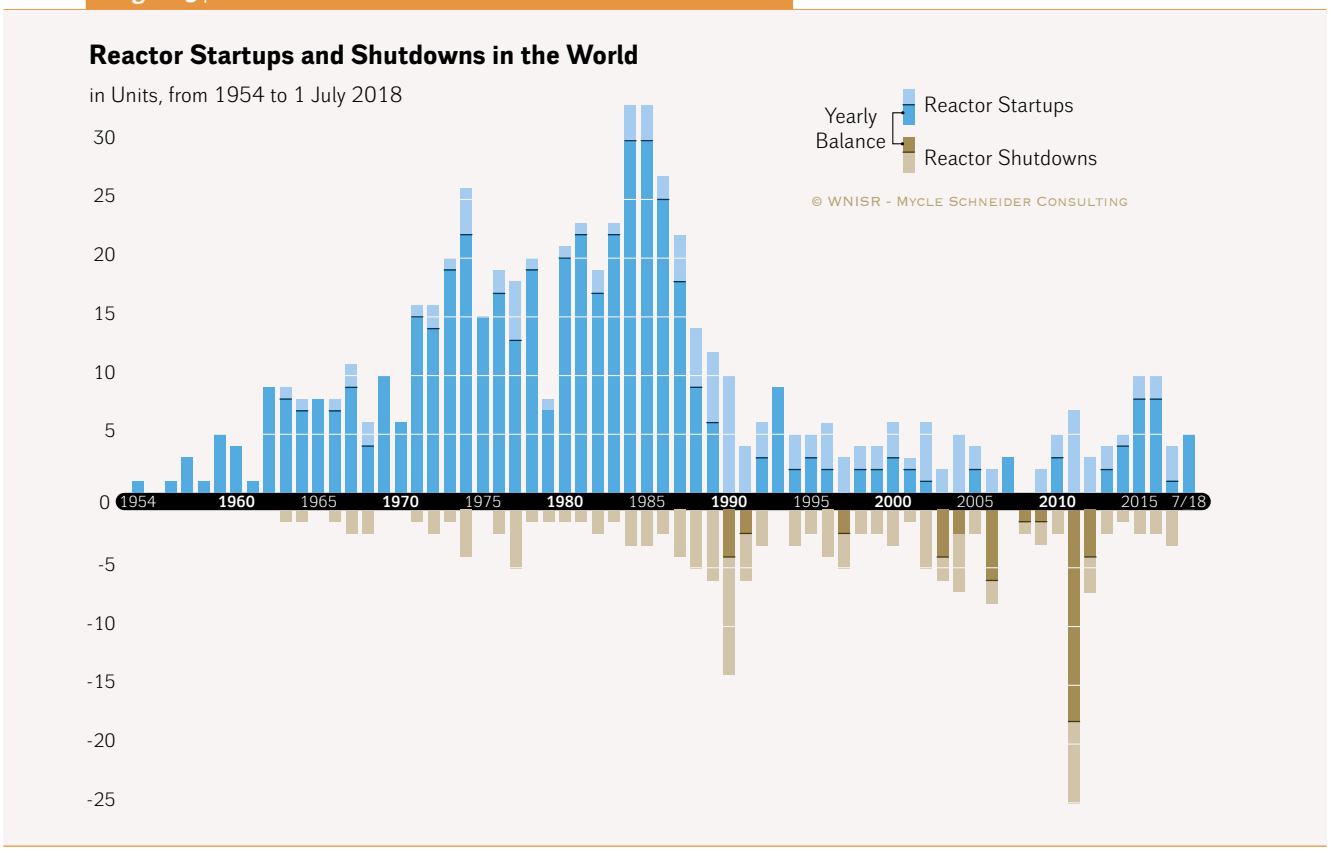
OPERATION, POWER GENERATION, AGE DISTRIBUTION

Since the first nuclear power reactor was connected to the Soviet power grid at Obninsk on 27 June 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 shutdowns outweighed the number of startups. The 1991-2000 decade produced far more startups than shutdowns (52/30), while in the decade 2001-2010, startups did not match shutdowns (32/35). Furthermore, after 2000, it took a whole decade to connect as many units as in a single year in the middle of the 1980s. Between 2011 and mid-2018, the startup of 48 reactors—of which 29 (60 percent) in China alone—outpaced by six the closure of 42 units over the same period. (See Figure 3).

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).

Three reactors were closed in 2017, respectively the oldest unit in Germany (Gundremmingen-B, 33.5 years), South Korea (Kori-1, 40 years) and Sweden (Oskarshamn-1, 46 years).[24]

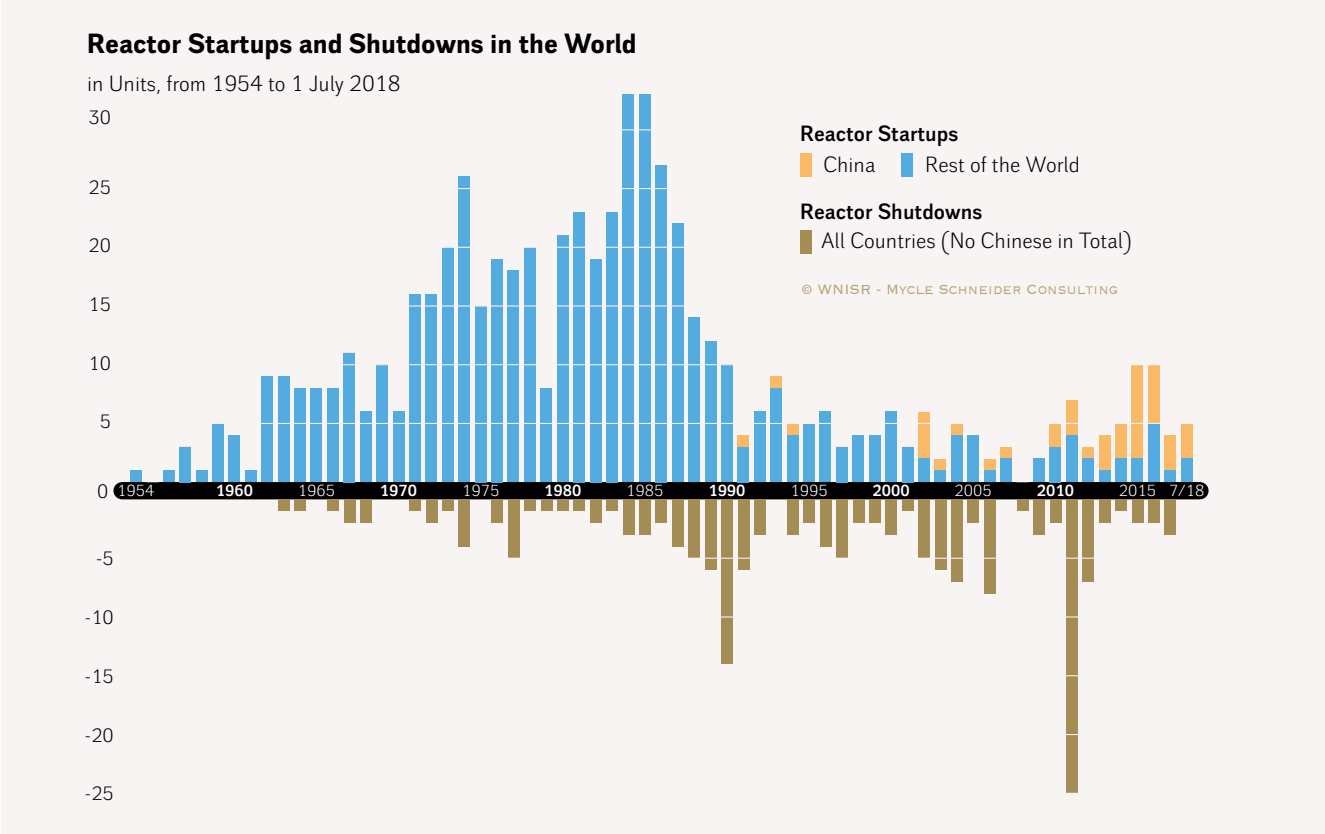
Figure 3 | Nuclear Power Reactor Grid Connections and Shutdowns



Sources: WNISR, with IAEA-PRIS, 2018

24 - WNISR considers shutdowns 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 the latest power generation.

Figure 4 | Nuclear Power Reactor Grid Connections and Shutdowns – The China Effect



Sources: WNISR, with IAEA-PRIS, 2018

In the first half of 2018, five reactors started up in the world, more than in the whole of 2017, while none has been closed. Three units were connected to the grid in China, including the first EPR (Taishan-1) and the first AP1000 (Sanmen-1) to start up in the world (see Figure 4). And two reactors started up in Russia, Leningrad 2-1, and Rostov-4 that began construction 35 years ago.[25]

The International Atomic Energy Agency (IAEA) continues to count 42 units in Japan in its total number of 453 reactors "in operation" in the world[26]; yet no nuclear electricity was generated in Japan between September 2013 and August 2015, and as of 1 July 2018, only nine reactors were operating (see Japan Focus for details). Nuclear plants provided only 3.6 percent of the electricity in Japan in 2017.

The WNISR keeps calling 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" remains is misleading. Steve Kidd, long-time industry strategist, agreed in a review of WNISR2016 in *Nuclear Engineering International* (*NEI*):

25 - *WNISR*, "35 Years After Construction Start Rostov-4 Connected to Russian Electricity Grid", 8 February 2018, see https://www.worldnuclearreport.org/35-Years-After-Construction-Start-Rostov-4-Reactor-Connected-to-Russian.html, 13 August 2018.

26 - IAEA, "Power Reactor Information System", International Atomic Energy Agency, Undated, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, accessed 28 July 2018.

> Including reactors as "operable" along with those definitely in service, when they have not generated power for many years (and don't even have a licence to do so) is clearly ridiculous.[27]

Maybe as a result of such criticism, the World Nuclear Association (WNA), in its second "World Nuclear Performance Report", has distinguished between "generating" and "not generating" nuclear generating capacity.[28]

The IAEA actually does have a reactor-status category called "Long-term Shutdown" or LTS.[29] 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 lists zero reactors in Japan 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 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 permanently close a reactor, the shutdown status starts with the day of the last electricity generation, and the WNISR statistics are modified retroactively accordingly.

Applying this definition to the world nuclear reactor fleet, as of 1 July 2018, leads to considering 26 Japanese units in LTO, seven less than in WNISR2017, as four reactors were restarted and three officially closed. WNISR considers all ten Fukushima reactors shut down permanently—while the operator Tokyo Electric Power Company (TEPCO) has written off the six Daiichi units, it keeps the four Daini reactors in the list of operational facilities. However, it is expected that the Daini plant will shortly be officially released for decommissioning. Annex 3 provides a detailed overview of the status of the Japanese reactor fleet. In December 2017, the IAEA finally moved the fast breeder reactor Monju, which had been officially closed in November 2016, from LTS to permanent shutdown. In August 2017, the IAEA also moved the Spanish reactor Garoña, that had not generated power since 2012, from LTS to permanent shutdown.

As of 1 July 2018, besides the 26 Japanese reactors, two reactors in India (Kakrapar-1 and -2), and one each in Argentina (Embalse), China (CEFR), France (Paluel-2)[30] and Taiwan (Chinshan-1) met the LTO criterion. Besides the restarts in Japan, one reactor each in France (Bugey-5) and Switzerland (Beznau-1), that were categorized as being in LTO status in WNISR2017, were re-

27 - Steve Kidd, "Nuclear power in the world – pessimism or optimism?", *NEI*, 13 October 2016, see http://www.neimagazine.com/opinion/opinionnuclear-power-in-the-world-pessimism-or-optimism-5031270/, accessed 13 August 2017.

28 - The World Nuclear Performance Report was launched by the World Nuclear Association (WNA) in 2016, "perhaps as a reaction to the success of successive WNISRs". In fact, in its September 2015 "Update for Members", WNA reported that its Fuel Report Working Group "discussed the merits of producing an annual nuclear capacity scenario update. Such an update would be a useful communications tool and a counter to the industry-critical World Nuclear Industry Status Report".

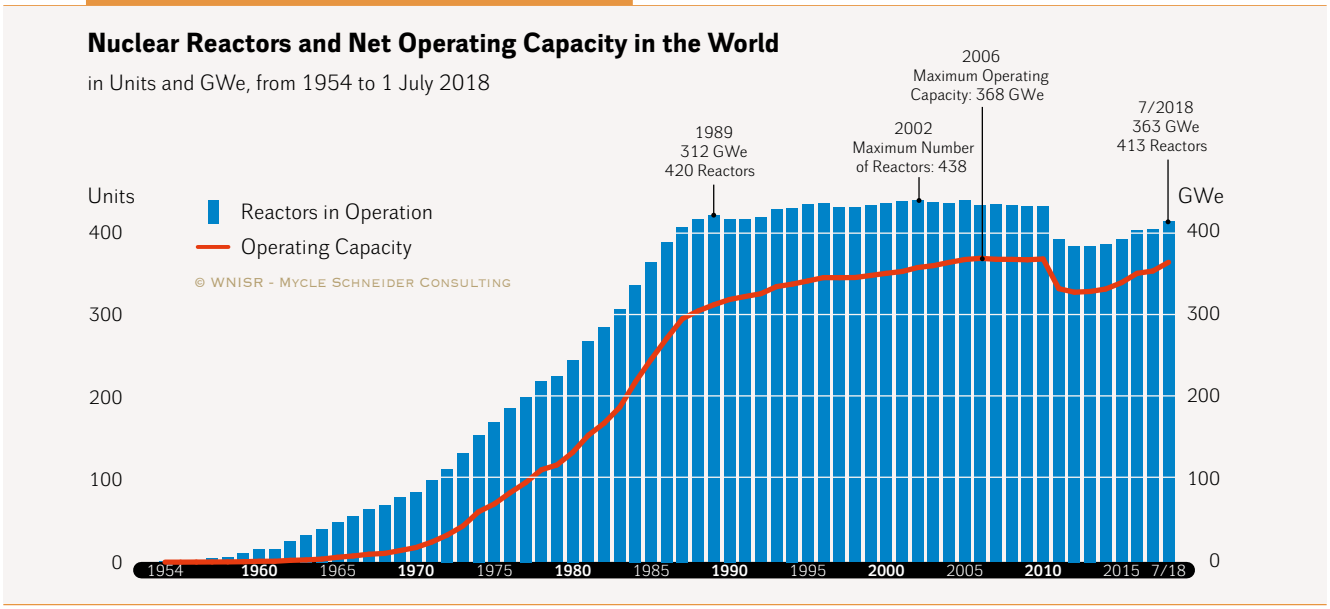
29 - See IAEA Glossary, at www.iaea.org/pris/Glossary.aspx, accessed 1 July 2016.

30 - After many delays, Paluel-2 was reconnected to the grid on 23 July 2018. See box in France Focus.

connected to the grid, and thus moved back to operational status. The total number of nuclear reactors in LTO as of 1 July 2018 is therefore 32; yet all are considered by the IAEA as "in operation".

As of 1 July 2018, a total of 413 nuclear reactors are operating in 31 countries, up 10 units from the situation in July 2017[31]. The current world fleet has a total nominal electric net capacity of 363.4 gigawatts (GW or thousand megawatts), up by 12 GW (+3.4 percent) from one year earlier (see Figure 5).

Figure 5 | World Nuclear Reactor Fleet, 1954–2018



Sources: WNISR, with IAEA-PRIS, 2018

For many years, the net installed capacity has continued to increase more than the net increase of numbers of operating reactors. This is a result of the combined effects of larger units replacing smaller ones and, mainly, technical alterations at existing plants, a process known as uprating.[32] In the United States alone, the Nuclear Regulatory Commission (NRC) has approved 164 uprates since 1977. The cumulative approved uprates in the United States total 7.9 GW, the equivalent of eight large reactors.[33]

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 alternatives become cheaper.

The use of nuclear energy remains limited to a small number of countries, with only 31 countries, or 16 percent of the 193 members of the United Nations, operating nuclear power plants. Close to half of the world's nuclear power countries are located in the European Union (EU), and, in 2017, they accounted for 31.5 percent of the world's nuclear production, with half of the EU generation in France.

31 - +7 startups, +6 restarts, –2 new LTOs, –1 shutdown

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

33 - U.S.NRC, "Approved Applications for Power Uprates", U.S. Nuclear Regulatory Commission, Updated 4 May 2018, see http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 28 July 2018.

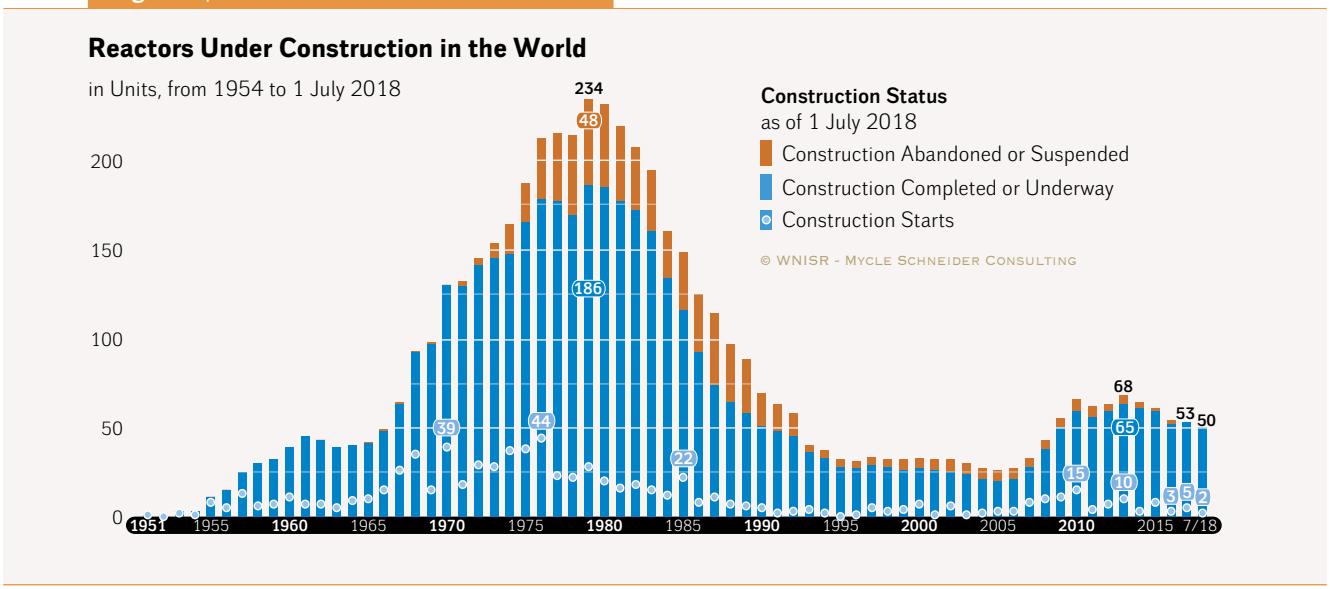
OVERVIEW OF CURRENT NEW-BUILD

As of 1 July 2018, 50 reactors are considered here as under construction, the lowest number in a decade, three fewer than WNISR reported a year ago, and 18 less than in 2013 (five units have already been abandoned since). Four in five reactors are built in Asia and Eastern Europe, and China alone has nearly a third of all reactors under construction (16 out of 50). In total, 15 countries are building nuclear plants, two more (Bangladesh and Turkey) than reported in WNISR2017 (see Table 1).

Five building projects were launched in 2017, two in India, and one each in Bangladesh, China (a non-commercial, demonstration fast breeder) and South Korea. As of 1 July 2018, there were two construction starts in the world so far in 2018, one in Russia, (Kursk-2-1) and Turkey (by a Russian company). Just prior to the official construction start, the Turkish investors pulled out (see details in the Turkey section of Potential Newcomers). It is remarkable that China has not launched a single new construction site for a commercial nuclear plant since December 2016.

Fifty is a relatively small number compared to a peak of 234 units listed as under construction—totaling more than 200 GW—in 1979. However, many of those projects (48) 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 now under construction in the world dropped again, by 3.8 GW to 49 GW, with an average unit size of 970 MW (see Annex 9 for details).

Figure 6 | Nuclear Reactors Under Construction



Sources: WNISR, with IAEA-PRIS, 2018

Table 1 | Nuclear Reactors "Under Construction" (as of 1 July 2018) [34]

Country	Units	Capacity MW net	Construction Starts	Grid Connection	Behind Schedule
China	16	15 450	2009 - 2017	2018 - 2023	8-9?
India	7	4 824	2004 - 2017	2018 - 2023	5
Russia	5	3 378	2007 - 2018	2019- 2022	4
South Korea	4	5 360	2009 - 2017	2018 - 2022	4
UAE	4	5 380	2012 - 2015	2020 – 2021?	3-4?
Belarus	2	2 218	2013 - 2014	2019 – 2020	1-2?
Pakistan	2	2 028	2015 - 2016	2020 - 2021	-
Slovakia	2	880	1985 - 1985	2018 - 2019	2
USA	2	2 234	2013 - 2013	2021 - 2022	2
Argentina	1	25	2014 - 2014	2020	1
Bangladesh	1	1 080	2017 - 2017	2023	-
Finland	1	1 600	2005 - 2005	2019	1
France	1	1 600	2007 - 2007	2020	1
Japan	1	1 325	2007 - 2007	?	1
Turkey	1	1 114	2018 - 2018	2023	-
World	50	48 496	1985- 2018	2018 - 2023	33-36

Note: This table does not contain suspended or abandoned constructions.

Sources: Compiled by WNISR, 2018

34 - For further details, see Annex 8.

CONSTRUCTION TIMES

CONSTRUCTION TIMES OF REACTORS *CURRENTLY UNDER CONSTRUCTION*

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

- As of 1 July 2018, the 50 reactors being built have been under construction for an average of 6.5 years, many of which are still far from completion.
- All reactors under construction in at least 7 (possibly 9) out of 15 countries have experienced mostly year-long delays. At least two thirds (33-36) of all building projects are delayed. Most of the remaining units under construction in the world, 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 two Pakistani construction sites.
- Of 33 reactors behind schedule, at least 14 have reported increased delays over the past year since WNISR2017.
- At the beginning of the year, 16 reactors were scheduled for startup in 2017, only four made it. Four reactors were scheduled to start up in the second half of 2017, only one did do so, the other three were connected to the grid in the first half of 2018.
- WNISR2017 noted a total of 19 reactors scheduled for startup in 2018. As of mid-2018, three of these reactors were connected to the grid (one of which was already connected in 2017) and seven have been officially delayed until at least 2019.
- Two projects have been listed as "under construction" for more than 30 years, Mochovce-3 and 4 in Slovakia. Rostov-4 in Russia was finally connected to the grid, 35 years after construction start.
- Four reactors have been listed as "under construction" for a decade or more, the Prototype Fast Breeder Reactor (PFBR) in India, the Olkiluoto-3 reactor project in Finland, Shimane-3 in Japan and the French Flamanville-3 unit.

It should be stressed that 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 illustrates, a significant share of investment and work can be carried out before even entering the official construction phase (see box in Focus U.K.).

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. 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. The four units completed in 2017 by the Chinese nuclear

industry in the homeland (3 units) and in Pakistan (1 unit) average an excellent 4.9 years construction time. This is only the second time since 2005 that world average construction time dropped below 5-year average. However, the five units that started up in the first half of 2018 show a much lower performance with an average of 13.4 years construction.

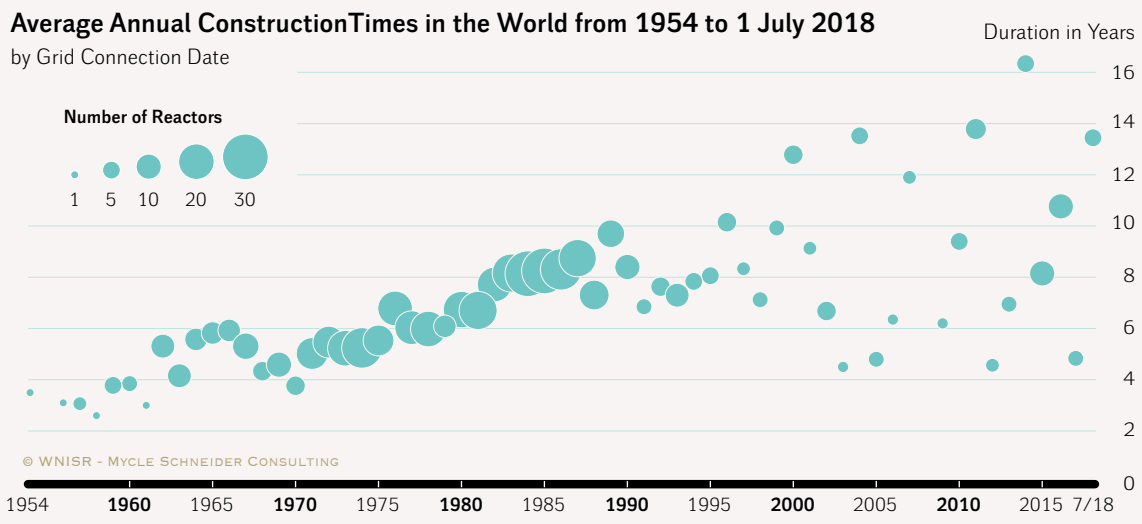
The longer-term perspective illustrates that short construction times remain the exceptions. Nine countries completed 55 reactors over the past decade after an average construction time of 10.1 years (see Table 2). While the average has hardly moved since WNISR2014, the range increased from 3.8-36.3 years to 4.1-43.5 years (the Watts Bar-2 in the U.S. record, which will remain the upper limit for some time to come).

Table 2 | Reactor Construction Times 2008-2018

Construction Times of 55 Units Started-up 2008-7/2018				
Country	Units	Construction Time (in Years)		
		Mean Time	Minimum	Maximum
China	31	6.0	4.1	11.2
Russia	7	24.0	8.1	35.1
India	5	9.8	7.2	14.2
South Korea	5	5.3	4.1	7.2
Pakistan	3	5.4	5.2	5.6
Argentina	1	33.0	33.0	
Iran	1	36.3	36.3	
Japan	1	5.1	5.1	
USA	1	43.5	43.5	
World	**55**	**10.1**	**4.1**	**43.5**

Sources: WNISR, with IAEA-PRIS, 2018

Figure 7 | Average Annual Construction Times in the World

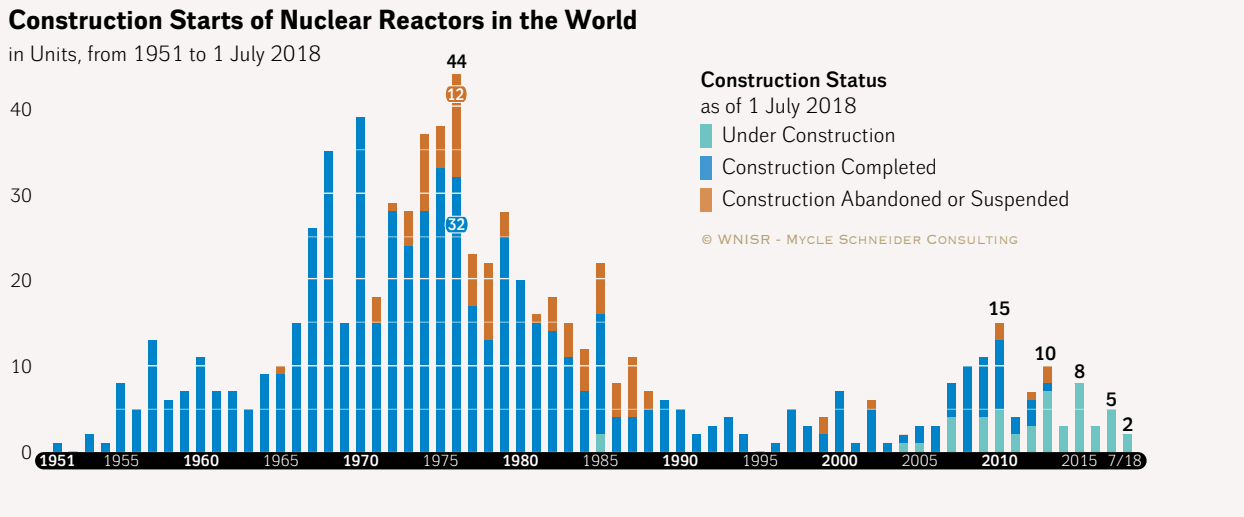


Sources: WNISR, with IAEA-PRIS, 2018

CONSTRUCTION STARTS AND CANCELLATIONS

The number of annual construction-starts[35] 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 alone—the highest level since 1985 (see Figure 8). That number dropped to 10 in 2013, eight in 2015, five in 2017 and two in 2018 as of mid-year.

Figure 8 | Construction Starts in the World



Sources: WNISR, with IAEA-PRIS, 2018

Seriously affected by the Fukushima events, China did not start any construction in 2011 and 2014. While Chinese utilities began building six more units in 2015, the number shrank to two in 2016, only a demonstration fast reactor in 2017 and none in 2018 as of midyear (see Figure 9). In other words, since December 2016, China has not started building any new commercial reactor.

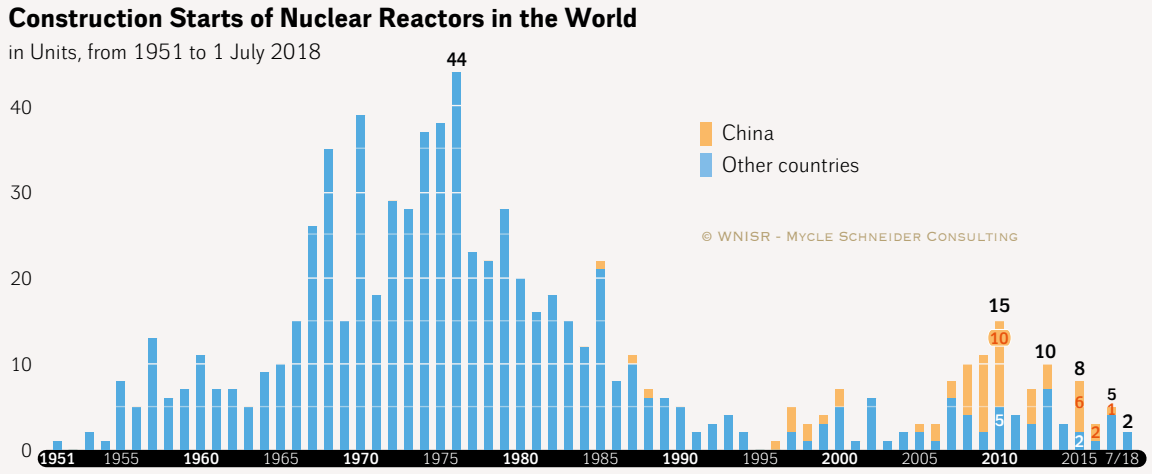
Over the decade 2008–2017, construction began on 76 reactors in the world (of which five have been cancelled), that is more than in the decade 1998-2007, when work started on 38 units (of which three have been abandoned). However, with 51 close to half of the 114 building starts over the past two decades were in China alone (see Figure 9).

In addition, 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 a multi-billion-dollar investment is only the latest example in a long list of failed nuclear power plant projects.

35 - Generally, a reactor is considered under construction, when the base slab of the reactor building is being concreted. Site preparation work, excavation and other infrastructure developments are not included.

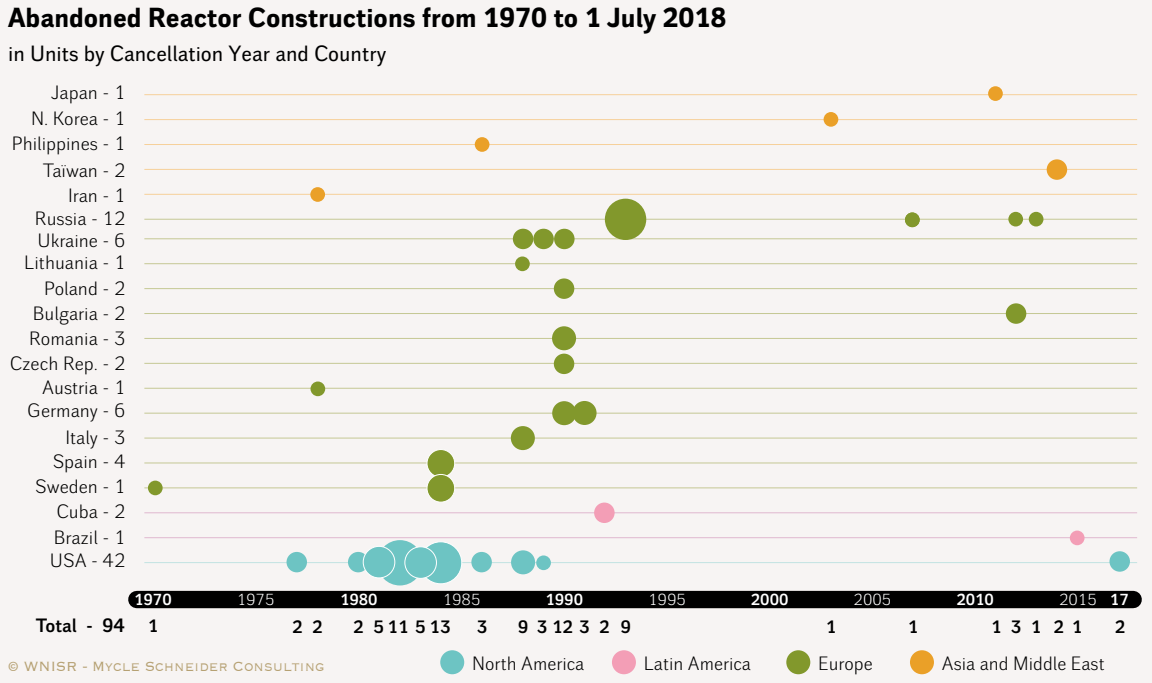
French Alternative Energies & Atomic Energy Commission (CEA) statistics through 2002 indicate 253 "cancelled orders" in 31 countries, many of them at an advanced construction stage (see also Figure 10). The United States alone accounted for 138 of these order cancellations.[36]

Figure 9 | Construction Starts in the World/China



Sources: WNISR, with IAEA-PRIS, 2018

Figure 10 | Cancelled or Suspended Reactor Constructions



Sources: WNISR, with IAEA-PRIS, 2018

Note: This graph only includes constructions that had already officially started.

36 - 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.

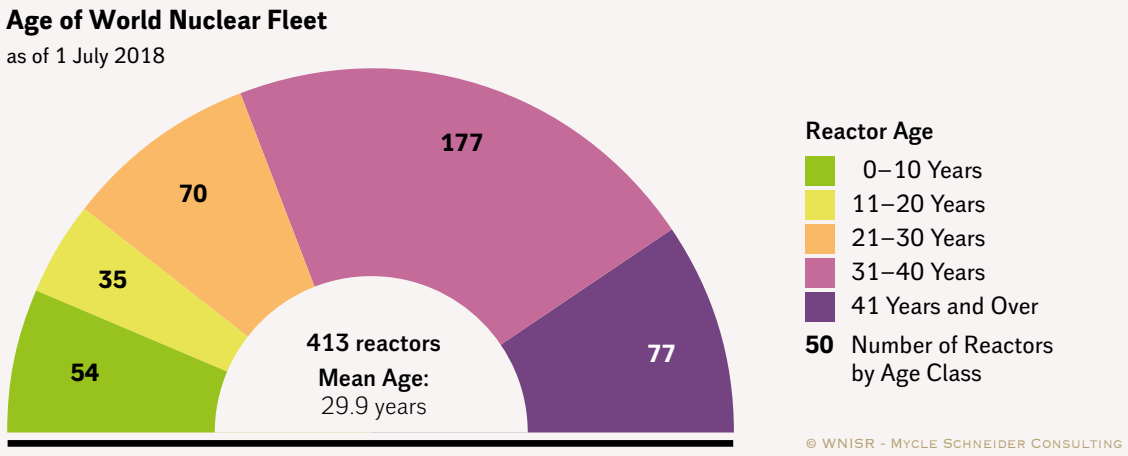
Of the 762 reactor constructions launched since 1951, at least 94 units (12 percent) in 20 countries had been abandoned as of 1 July 2018. The past decade shows about half of the historic abandoning rate of one in eight constructions, as five in 76 building sites officially started during that period were later given up at various stages of advancement.

Close to three quarters (66 units) of all cancelled projects were in four countries alone—the U.S. (42), Russia (12), Germany and Ukraine (six each). Some units were 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 any significant new-build *and* grid connection over many years, the average age (from grid connection) of operating nuclear power plants has been increasing steadily and at mid-2017 stands at 29.9 years, up from 29.3 a year ago (see Figure 11).[37] A total of 254 reactors (61.5 percent) have operated for 31 or more years, including 77 (18.5 percent) reaching 41 years or more.

Figure 11 | Age Distribution of Operating Reactors in the World



Sources: WNISR, with IAEA-PRIS, 2018

Some nuclear utilities envisage average reactor lifetimes of beyond 40 years up to 60 and even 80 years. In the United States, reactors are initially licensed to operate for 40 years, but nuclear operators can request a license renewal for an additional 20 years from the Nuclear Regulatory Commission (NRC).

As of 4 May 2018, 87 of the 99 operating U.S. units have received an extension, with another four applications for five reactors under NRC review. Since WNISR2017, one license renewal for two reactors (South Texas-1 and -2) was granted, and no additional application request was filed. The Diablo Canyon-1 and -2 application was withdrawn by the licensee on 7 March 2018. The two units can continue operating until their current licenses expire (2 November 2024 for Unit 1, and 20 August 2025 for Unit 2).[38]

In the U.S., only two of the 34 units that have been shut down had reached 40 years on the grid—Vermont Yankee, closed in December 2014, at the age of 42, and Fort Calhoun, shut down in October 2016, after 43 years of operation. Both 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

37 - WNISR calculates reactor age from grid connection to final disconnection from the grid. In WNISR statistics, "startup" is synonymous with grid connection and "shutdown" with withdrawal from the grid. In previous editions of the WNISR, the reactor age was automatically rounded to the year. 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.

38 - U.S.NRC, "Status of License Renewal Applications and Industry Activities", Updated 4 May 2018, see http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 29 July 2018.

reactors connected to the grid in the U.S. never reached their initial design lifetime of 40 years. On the other hand, of the 99 currently operating plants, 44 units have operated for 41 years or more; thus, half of the units with license renewals have already entered the life extension period, and that share is growing rapidly with the mid-2018 average age of the U.S. operational fleet at 38.1 years (see United States Focus).

Many other countries have no specific time limits on operating licenses. In France, where the country's first operating Pressurized Water Reactor (PWR) started up in 1977, reactors must undergo in-depth inspection and testing every decade against reinforced safety requirements. The French reactors have operated for 33.4 years on average, and the oldest have completed the process with the French Nuclear Safety Authority (ASN) evaluating each reactor before allowing a unit to operate for more than 30 years. They could then operate until they reach 40 years, which is the limit of their initial design age. However, the assessments are years behind schedule. The French utility Électricité de France (EDF) clearly prioritizes lifetime extension to 50 years over large-scale new-build.

EDF's approach to lifetime extension is currently under review by ASN's Technical Support Organization, the Institute for Radiation Protection and Nuclear Safety (IRSN) and is now scheduled to be examined by its expert committees (Groupes Permanents) in 2018 and 2019. ASN plans to provide its opinion on the general assessment outline by 2020. In addition, lifetime extension beyond 40 years requires site-specific public enquiries.

Current French energy legislation requires planning to limit the nuclear share in power production to 50 percent by 2025. The implementation of this legislation—even if the 2025 target was to be delayed as is currently discussed—in a context of stagnating electricity consumption, would mean the closure of about one third of the French reactor fleet. In other words, many of the lifetime extensions would become obsolete (see France Focus for details). A particularly difficult aspect of the lifetime management in France is that the units licensed to use plutonium-uranium mixed oxide fuel (MOX) are also the oldest reactors. The criteria for selection of reactors to be closed remain under discussion.

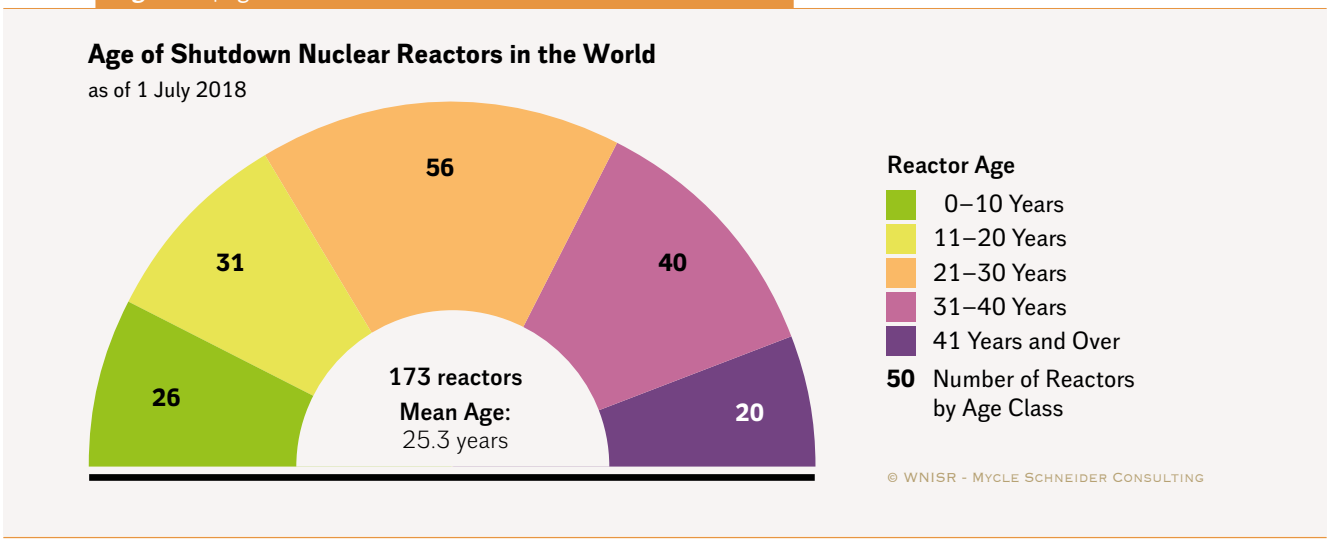
In assessing the likelihood of reactors being able to operate for 50 or 60 years, it is useful to compare the age distribution of reactors that are currently operating with those that have already shut down (see Figure 11 and Figure 12). As of mid-2018, 77 of the world's reactors have operated for 41 years or more, and a total of 81 that have already passed their 40-year lifetime are considered in lifetime extension.[39] As the age pyramid illustrates, that number could rapidly increase over the next few years. A total of 254 units, 20 more than in WNISR2017, have already reached or exceeded age 31.

The age structure of the 173 units already shut down completes the picture. In total, 60 of these units operated for 31 years or more, and of those, 20 reactors operated for 41 years or more (see Figure 12) Many units of the first-generation designs only operated for a few years. Considering that the average age of the 173 units that have already shut down is about 25 years, plans to extend the operational lifetime of large numbers of units to 40 years and far beyond seemed rather optimistic. However, the operating time prior to shutdown has clearly increased continuously. But while the *average* annual age at shutdown got close to 40 years, it only passed

39 - WNISR considers the age starting with grid connection, and while figures used to be rounded by half-years, as of WNISR2016 they are rounded by the tenth of the year.

that age twice so far: in 2014, when the only such unit shut down that year (Vermont Yankee in the U.S.) after 42 years of operation; and in 2016, with two reactors shutting down at age 43 (Fort Calhoun, U.S.) and 45 (Novovoronezh, Russia) respectively.

Figure 12 | Age Distribution of Shut Down Nuclear Power Reactors



Sources: WNISR, with IAEA-PRIS, 2018

As a result of the Fukushima nuclear disaster, 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, a month before the catastrophe began. Four days after the accidents in Japan, the German government ordered the shutdown of seven reactors that had started up before 1981. These reactors, together with another unit that was closed at the time, 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 had an impact on previously assumed extended lifetimes in other countries as well, including in Belgium, Switzerland, and Taiwan. And more recently, in the first half of 2017, South Korea's incoming President Moon shut down the country's oldest reactor (Kori-1), explicitly at the age of forty, ruling out lifetime extensions in the future. Sweden also closed its oldest unit, Oskarshamn-1 at age 46. And Germany shut down its oldest reactor, Gundremmingen-B, at year-end 2017 at age 33. The average age of these three units remains with 39.9 years again just below 40.

LIFETIME PROJECTIONS

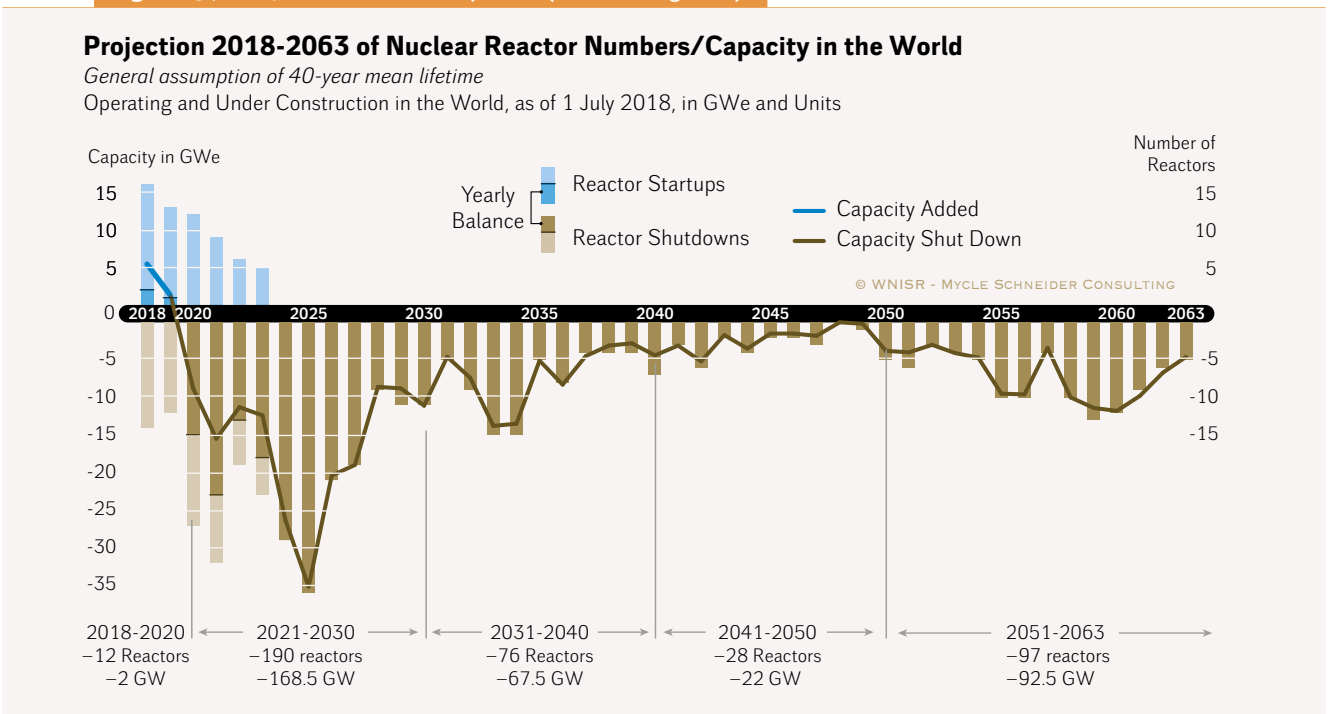
Many countries continue to implement or prepare for lifetime extensions. As in previous years, WNISR has therefore created two lifetime projections. A first scenario (40-Year Lifetime Projection, see Figure 13), assumes a general lifetime of 40 years for worldwide operating reactors (not including reactors in Long-Term Outage (LTO), as they are not considered operating). The 40-year number corresponds to the design lifetimes of most operating reactors. Some countries have legislation (Belgium) or policy (South Korea) in place that limit operating lifetime to 40 years.

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 14) 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 on line over the next decades to offset closures and simply maintain the same number of operating plants and capacity. With all units under construction scheduled to have gone online, installed nuclear capacity would decrease by 2 GW by 2020, which is marginal, and below the uncertainty level. In total, 12 additional reactors (compared to the end of 2017 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. Compared to the situation four years ago, the number of additional units necessary to break even by 2020 shrank by 18. In fact, construction started on 21 units between 2014 and mid-2018, and Japan restarted nine reactors (none were operating in 2014). The additional capacity needed to maintain the status quo by 2020 declined by 5.5 GW.

Figure 13 | The 40-Year Lifetime Projection (not including LTOs)



Sources: Various sources, compiled by WNISR, 2018

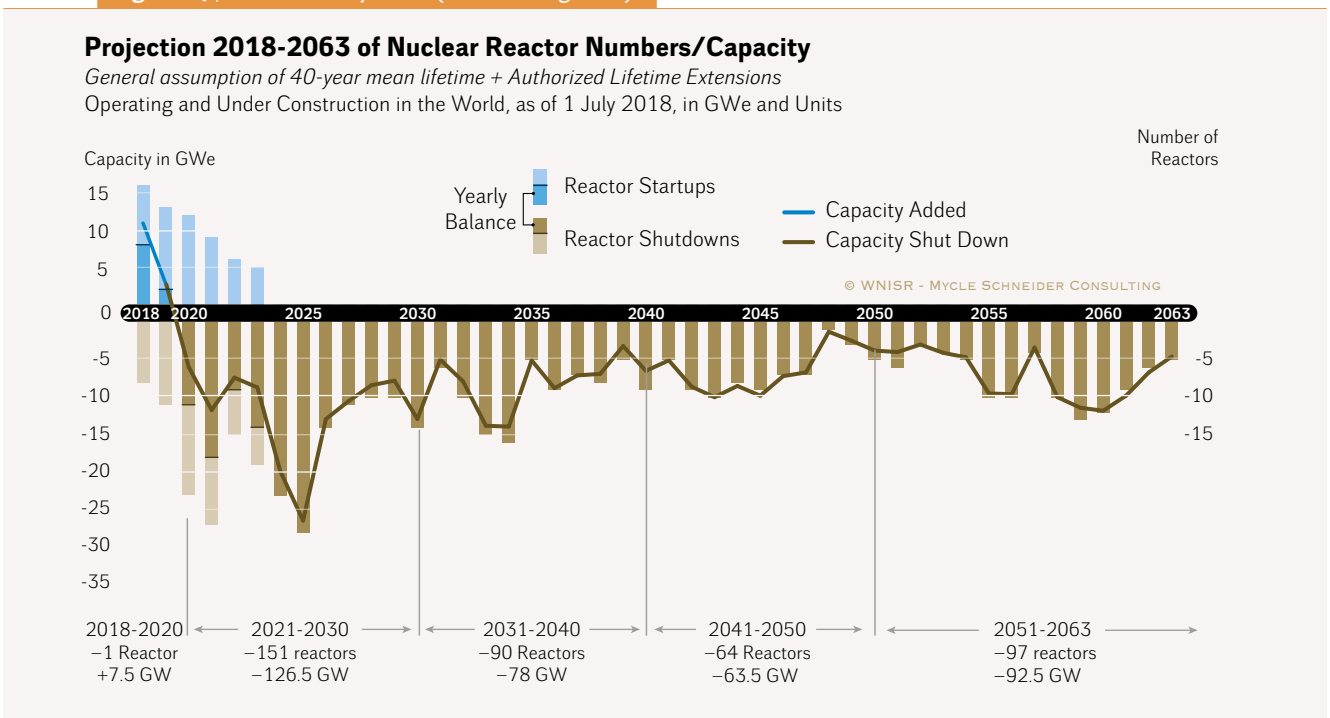
In the following decade to 2030, 190 additional new reactors (168.5 GW) would have to be connected to the grid to maintain the status quo, around 3.5 times the rate achieved over the past decade (55 units between 2008 and mid-2018). The situation is quasi-identical to the situation in 2014, when the corresponding projections indicated a need for 188 reactors, with a somewhat higher total capacity of 178 GW.

The achievement to stabilize the situation by 2020 will depend on the number of Japanese and other reactors currently in LTO coming back online, as it is technically impossible to start and complete construction of a new plant within a two-and-a-half-year period.

As a result, the number of reactors in operation will likely more or less stagnate at best, unless Japanese and other reactors currently in LTO come back online, and lifetime extensions far beyond 40 years become widespread. Such generalized lifetime extensions are the objective of the nuclear power industry, and, especially in the U.S., there are numerous more or less successful attempts to subsidize uneconomic nuclear plants (see detailed analysis in United States Focus).

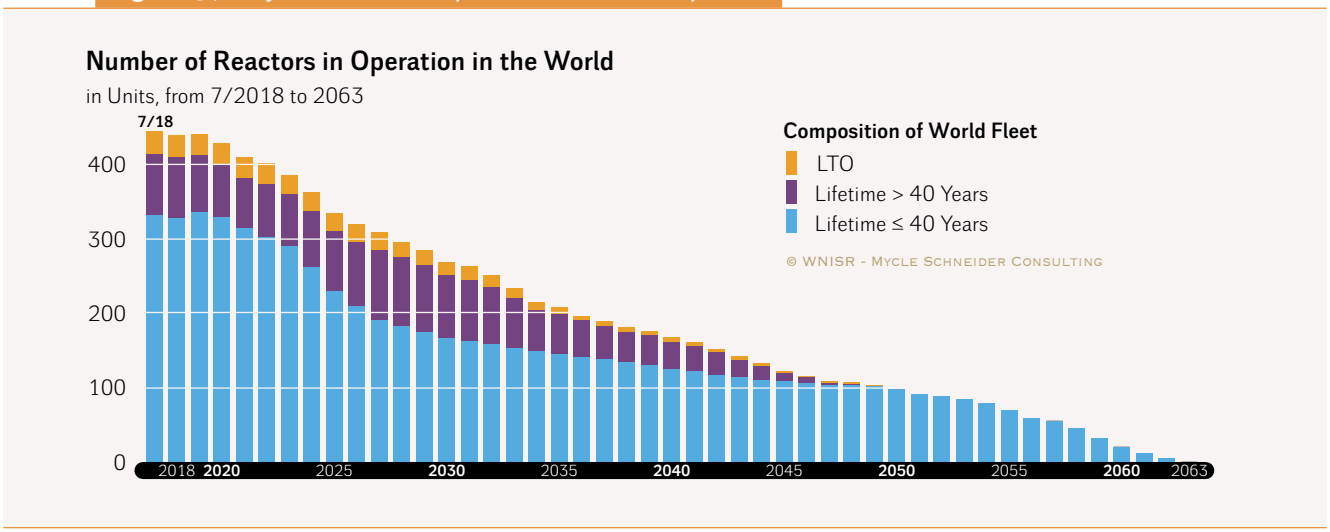
Developments in Asia, and particularly in China, do not fundamentally change the global picture. Reported figures for China's 2020 target for installed nuclear capacity have fluctuated between 40 GW and 120 GW in the past. The freeze of construction initiation for almost two years and new siting authorizations for four years has significantly reduced Chinese ambitions. China will clearly miss the latest official target of 58 GW for 2020.

Figure 14 | The PLEX Projection (not including LTOs)



Sources: Various sources, compiled by WNISR, 2018

Figure 15 | Forty-Year Lifetime Projection versus PLEX Projection



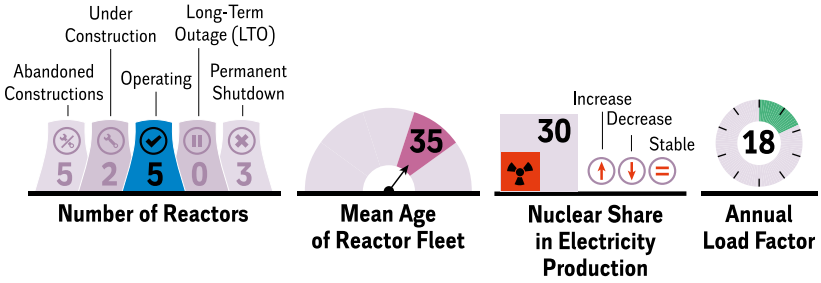
Sources: WNISR, with IAEA-PRIS, 2018

Every year, we also model a scenario, in which all currently licensed lifetime extensions and license renewals (mainly in the United States) 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 shutdown date has been announced. By 2020, the net number of operating reactors would still decline by one unit, but the installed capacity would grow by 7.5 GW (less than half of the WNISR2017 projection of 16.5 GW).

In the following decade to 2030, still 151 new reactors (126.5 GW) would have to start up to replace shutdowns. That is somewhat better than the projections in WNISR2017 with 163 reactors/142 GW. However, the new projection would still mean, in the coming decade to triple the number of units built over the past decade (see Figure 13, Figure 14 and the cumulated effect in Figure 15). In the meantime, construction starts have declined.

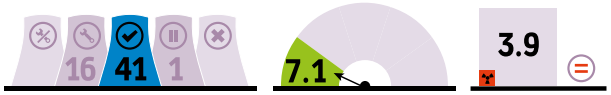
FOCUS COUNTRIES

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



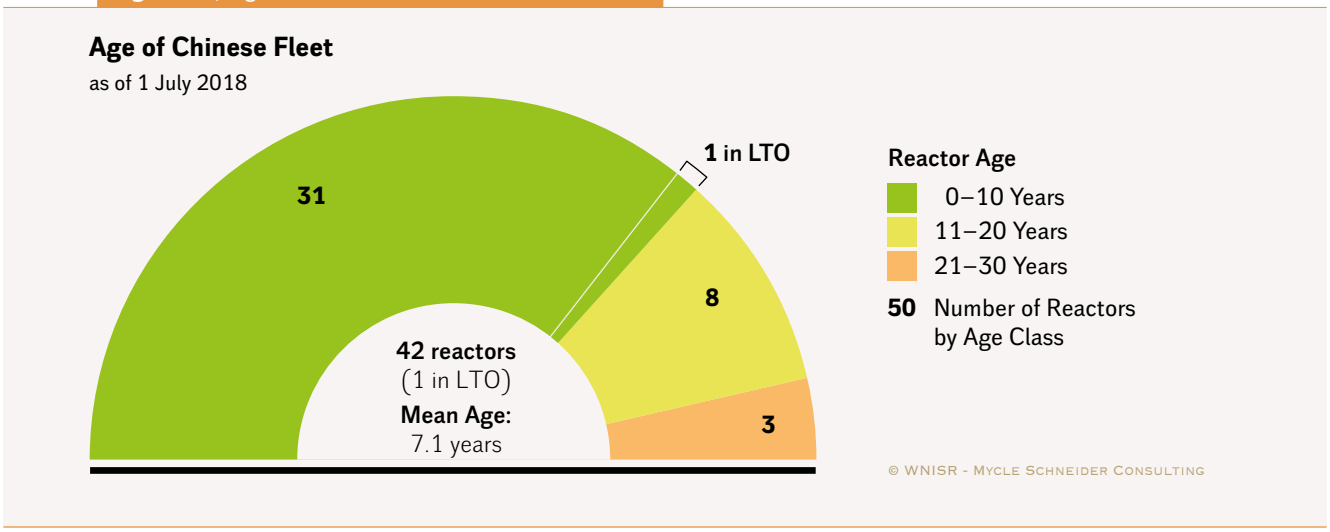
The following chapter provides an in-depth assessment of seven countries: China, France, Germany, Japan, South Korea, United Kingdom (U.K.) and the United States (U.S.). They represent about two thirds of the global reactor fleet (63 percent of the units and 70 percent of the installed capacity) and six of the world's nine largest nuclear power producers.

CHINA FOCUS



Over the last few years, China has moved to having the third largest number of operating reactors, just behind the United States and France.[40] As of 1 July 2018, China had 41 operating reactors with a total net capacity of 38 GW. This includes the first two operational Western designed Generation III+ reactors: the European Pressurized Water (EPR) reactor at Taishan that was connected to the grid on 29 June 2018 and the AP1000 reactor at Sanmen that was connected on 30 June 2018. The Chinese reactor fleet is very young with an average age of 7.1 years (see Figure 16).

Figure 16 | Age Distribution of Chinese Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2018

40 - The IAEA lists Japan as having more operating reactors, but as discussed elsewhere in this report and earlier editions of WNISR, this is misleading and most of them are in Long-Term Outage (LTO) status; many of them will never be restarted. Indeed, with the March 2018 decision to permanently close the Ikata-2 reactor, nine commercial reactors have been declared as earmarked for decommissioning in Japan. This is in addition to the reactors at Fukushima Daiichi and the fast breeder reactor at Monju.

In 2017, nuclear power contributed 232.8 TWh—up by 18 percent from 197.8 TWh in 2016—which constituted 3.9 percent of all electricity generated in China. The share of nuclear energy has gone up from 3.6 percent in 2016.[41] Renewable energy sources increased their contribution also significantly. In 2017, wind energy contributed 306 TWh, up by 26 percent from its contribution in 2016 of 242 TWh, while solar energy contributed 118 TWh, up by 75 percent from 67.4 TWh in 2016.[42] Electricity generated by wind energy has long exceeded the nuclear contribution, and now solar energy is rapidly catching up, now already generating almost half as much as nuclear power plants. However, "curtailment", or the mismatch between energy generation by solar panels and wind turbines and the grid's ability to transmit the electricity put out by these plants, continues to be a challenge.

The China Experimental Fast Reactor (CEFR) is not primarily a power generating reactor. However, as it was connected to the grid in 2011 at about 40 percent power and achieved full power for 72 hours starting 18 December 2014[43], it is included in the WNISR. According to one source in China, the reactor has not been operating for several years, as it is lacking fuel. There are also other sources pointing to fuel issues.[44] In January 2017, the China Institute of Atomic Energy entered into an agreement with Russian Rosatom's subsidiary TVEL to fabricate fuel for CEFR in 2017 and 2018 for loading into the reactor in 2019.[45] We have therefore decided to take it off the operational status and put it into Long-Term Outage (LTO). The figure of 41 operational reactors mentioned above takes into account this change of status.

China has the largest number of nuclear reactors under construction—16 reactors with a total capacity of 15.4 GW. As has been the case for some years now, at least half of these are delayed. This includes all the Western designed Generation III+ reactors being constructed at Taishan, Sanmen, and Haiyang. The reactors that were connected to the grid on 29 and 30 June 2018 at Taishan and Sanmen respectively were also delayed (see Annex 2 and Annex 9).

In 2009, Zhang Guobao, vice minister in charge of the National Development and Reform Commission and also head of the National Energy Administration, declared that the Sanmen project was "the biggest energy cooperation project between China and the United States".[46] At that time, the first generating unit was to "be put into operation in 2013, and the second, in 2014"; in all, the plant was to have six units.[47] After many announcements about imminent starts, the first Sanmen unit started the process of being loaded with fuel finally in April 2018.[48] According to Westinghouse, which designed the AP1000, construction of the plant "had been complete for more than a year" but "fuel loading… had been held up since last summer because

41 - IAEA, "Nuclear Power Reactors in the World: 2017 Edition", International Atomic Energy Agency, 2017.

42 - *China Energy Portal*, "2017 electricity & other energy statistics", 6 February 2018, see https://chinaenergyportal.org/2017-electricity-energy-statistics/, accessed 14 May 2018.

43 - *Xinhua*, "China experimental fast reactor runs at full capacity", *China Securities Journal*, *19 December 2014, see* http://www.cs.com.cn/english/ei/201412/t20141219_4595461.html, accessed 28 May 2018.

44 - Mark Hibbs, "Rethinking China's Fast Reactor", *Arms Control Wonk*, 17 February 2017, see https://www.armscontrolwonk.com/archive/1202830/rethinking-chinas-fast-reactor/, accessed 28 May 2018.

45 - *NEI*, "Russia to supply more fuel for China's fast reactor", 5 January 2017, see http://www.neimagazine.com/news/newsrussia-to-supply-more-fuel-for-chinas-fast-reactor-5709961, accessed 28 May 2018.

46 - *Xinhua, "China starts building 3rd-generation nuclear power reactors using Westinghouse technologies", People's Daily Online, 20 April 2009, see* http://en.people.cn/90001/90778/90857/90860/6640730.html, accessed 14 May 2018.

47 - Ibidem.

48 - *Bloomberg*, "Westinghouse's Marquee Reactor in China Begins Fuel Loading", 25 April 2018, see https://www.bloomberg.com/news/articles/2018-04-25/westinghouse-s-marquee-reactor-in-china-begins-fuel-loading, accessed 25 April 2018.

of new questions raised by regulators".[49] There has been a history of safety concerns regarding the AP1000s being constructed in Sanmen and Haiyang dating back to around five years.[50] There have also been problems with construction. Previous volumes of the WNISR have discussed some of the reasons for the concern about safety and problems with construction. As mentioned above, Sanmen1 was connected to the grid on 30 June 2018.

It has also become more evident, since Westinghouse filed for bankruptcy protection, that a key reason for the delays was that the Westinghouse design was far from complete when the projects commenced. Indeed, in China, reportedly construction "had progressed to the point of erecting structures and still the design hadn't been completed".[51] Starting construction with incomplete designs is not a new occurrence in the history of nuclear power, and the experiences in Sanmen and Taishan (and, for that matter, Vogtle and V. C. Summer in the U.S.) only serve as reminders that the nuclear industry keeps repeating prior mistakes in project management.

Projections for the costs of the AP1000 reactors have, naturally, risen. In its environmental impact assessment for the Sanmen project from August 2017, China's National Nuclear Safety Administration "projected a total project price tag of 52.5 billion yuan (US$8.3 billion)—more than double the original budget for the two units of 25 billion yuan".[52] The cost estimate for the project has likely increased further.

This increased cost must be seen in the context of changing electricity power prices in China. In April of this year, Sanmen "cleared the annual power exchange auction in Zhejiang province, making it eligible to sell 766 gigawatt hours of output during 2018 at a price of 0.385 yuan per kilowatt-hour (US$0.061/kWh), roughly 10 percent less than the standard nuclear tariff of 0.43 yuan/kWh".[53] In other words, the project may prove unprofitable. It is also worth noting that 766 gigawatt hours represents less than 9 percent of the net output of an AP1000, if it were to operate at full capacity for a whole year.

Earlier in April 2018, the other imported reactor design under construction in China, the EPR being built at Taishan, also received permission for fuel loading.[54] The reactor was connected to the grid on 29 June 2018. Unit 1 of Taishan was originally scheduled to be completed in 2013 and it was also delayed due to a combination of construction problems and safety concerns. According to China General Nuclear Power Corporation (CGN-Power), Taishan Unit 2

49 - William Freebairn, "Chinese nuclear reactor starts loading fuel after delay: Westinghouse", *Platts, 25 April 2018, see* https://www.platts.com/latest-news/electric-power/washington/chinese-nuclear-reactor-starts-loading-fuel-after-21888129, accessed 26 April 2018.

50 - Eric Ng, "China nuclear plant delay raises safety concern", *South China Morning Post*, 7 October 2013, see http://www.scmp.com/business/china-business/article/1325973/china-nuclear-plant-delay-raises-safety-concern, accessed 4 April 2015; and David Stanway, "China nuclear reactor delayed again on 'safety concerns': China Daily", *Reuters, 13 February 2018, see* https://www.reuters.com/article/us-china-nuclear/china-nuclear-reactor-delayed-again-on-safety-concerns-china-daily-idUSKBN1FX02P, accessed 9 April 2018.

51 - Anya Litvak, "Westinghouse sold an unfinished product, then the problems snowballed", *Pittsburgh Post-Gazette*, 23 October 2017, see http://www.post-gazette.com/powersource/companies/2017/10/23/Westinghouse-sold-an-unfinished-product-then-the-problems-snowballed/stories/201710290008, accessed 15 May 2018.

52 - C. F. Yu, "First AP1000 Moves to Commercialization", 27 April 2018.

53 - *NIW*, "Weekly Roundup", 20 April 2018.

54 - David Stanway, "China begins fuel loading at long-delayed EPR nuclear project", *Reuters*, 11 April 2018, see https://www.reuters.com/article/china-nuclear-cgn/corrected-china-begins-fuel-loading-at-long-delayed-epr-nuclear-project-idUSL3N1RO1Z8, accessed 11 April 2018.

is expected to commence commercial operations in 2019.[55] The cost estimate of the Taishan nuclear plant has also gone up; earlier this year, CGN reported "the total capital cost to date of Taishan-1 and -2 at 71.38 billion yuan (US$11 billion) or 20,000 yuan per kilowatt — 40 percent over the original estimate"[56].

Although there are reportedly four AP1000 projects waiting for approval in China,[57] there is no question that these delays and safety concerns have significantly diminished the prospects for western nuclear vendors to sell more reactors to China. Meanwhile, China has also started to produce fuel domestically for the AP1000s coming up in Sanmen and Haiyang.[58] The capability goes back to "a US$35 million deal announced in January 2011" according to which Westinghouse agreed to "design, manufacture and install fuel fabrication equipment" for China North Nuclear Fuel, a subsidiary of China National Nuclear Corporation, with the aim of "supplying subsequent fuel for the Sanmen and Haiyang units".[59] China North Nuclear Fuel has signed a contract to "supply batches of fuel assemblies for the second, third and fourth fuel cycles of Sanmen units 1 and 2".[60] Consequently, Westinghouse cannot count on sales of fuel assemblies to China for revenue generation in the future.

Construction of domestically designed reactors fared a little better. This becomes clear from the annual document called the *Energy Work Guidance Opinion* published by China's National Energy Administration (NEA). In February 2017, this document announced that during the year "construction will be completed of the Sanmen1 and Haiyang-1 AP1000 units, the Taishan-1 EPR and the Fuqing-4 and Yangjiang-4 CPR-1000 units. These, together with 'other projects', will add some 6.41 GWe of nuclear generating capacity".[61] Compare that statement with the corresponding prediction put out in March 2018: "China's installed nuclear generating capacity would be boosted by a total of 6 GWe this year with the start-up of the Sanmen1 and Haiyang-1 AP1000s, the Taishan-1 EPR, the Tianwan-3 VVER-1000 and the Yangjiang-5 ACPR1000".[62] Seen together, it is clear that the only predictions from the NEA that came true was the completion of the Fuqing-4 and Yangjiang-4 CPR-1000 units, which were declared as being in commercial operation on 17 September and 15 March 2017 respectively.

Among the reactors slated to be completed in 2018, apart from Taishan-1 and Sanmen1 already discussed, Tianwan-3 has already been declared operational. This is a VVER-1000, a Pressurized Water Reactor imported from Russia and its origins date back to "a 1992 cooperation agreement between China and Russia".[63] Construction of units 1 & 2 started "in

55 - CGN, "Inside Information: Construction Progress of Taishan Nuclear Power Generating Units", 29 December 2017, see http://en.cgnp.com.cn/encgnp/c100884/201712/883ae364eec7473fb27158348af7c13a/files/37c9323477e249f2baab22c63df65dd7.pdf, accessed 11 April 2018.

56 - C. F. Yu, "Taishan-1 Approval — Shifting Priorities On Newbuild?", *NIW*, 13 April 2018.

57 - Yu, "First AP1000 Moves to Commercialization".

58 - *WNN*, "Chinese plant produces AP1000 reload assemblies", 8 January 2018, see http://www.world-nuclear-news.org/UF-Chinese-plant-produces-AP1000-reload-assemblies-0801175.html, accessed 14 May 2018.

59 - Ibidem.

60 - Ibidem.

61 - *WNN*, "China sets out nuclear plans for 2017", 2 March 2017, see http://www.world-nuclear-news.org/NP-China-sets-out-nuclear-plans-for-2017-0203174.html, accessed 15 May 2018.

62 - *WNN*, "China to start building up to eight reactors in 2018", 7 March 2018, see http://www.world-nuclear-news.org/NP-China-to-start-building-up-to-eight-reactors-in-2018-0703185.html, accessed 15 May 2018.

63 - *WNN*, "Dome installed on Tianwan 6 containment building", 8 May 2018, see http://www.world-nuclear-news.org/NN-Dome-installed-on-Tianwan-6-containment-building-0805184.html, accessed 15 May 2018.

October 1999, and the units were commissioned in June 2007 and September 2007 respectively" and "first concrete for unit 3 was poured in December 2012, while construction of the fourth unit began in September 2013".[64] However, units 3 and 4 might be the last of the VVERs that China is importing. The further units at the site, Tianwan-5 and Tianwan-6, are domestically designed 1080 MWe ACPR1000 reactors.

One exception to the relatively better experience with domestic reactor designs is the case of the High Temperature Gas Cooled Reactor (HTR) being constructed at Shandong, which continues to be delayed. In January 2018, it was reported that it "is expected to be connected to the grid and start electricity generation this year".[65] 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 estimated costs of electricity generation at the HTR are nearly 40 percent higher than at light water reactors.[66] In large part that is because "the current construction cost of the Shidao Bay HTGR is estimated at around 40,000 yuan (US$5,803) per kilowatt, compared to the targeted 17,000 yuan (US$2,466)/kW for China National Nuclear Corporation's (CNNC) inaugural Hualong-One Pressurized Water Reactors (PWRs) at Fuqing, in Fujian, and around 21,000 yuan (US$3,047)/kW for the first-of-a-kind AP1000s at CNNC's Sanmen plant in Zhejiang".[67] Of course, the actual costs of the AP1000 projects were higher than the targeted values. Promoters of the HTR tout "the potential use of the reactors" in "different industrial applications, from combined-heating and power plants, hydrogen production, sea water desalinization to enhanced oil and gas recovery".[68] But this plan to explore alternate markets is in itself a sign that even its promoters don't see the HTR doing well in the electricity market.

> *"no new construction on a commercial reactor was launched since December 2016"*

As a result of the delays and slowdown in construction starts—no new construction on a commercial reactor was launched since December 2016, only a demonstration fast reactor (CFR-600) got underway in December 2017—it is now clear that China will not meet its declared target of an installed capacity of 58 GW of nuclear power by 2020. Even high-level officials have started being open about this. For example, in a November 2017 meeting of the Chinese Society for Electrical Engineering, Shi Lishan, deputy director of the Nuclear Power Division of the National Energy Administration, admitted, "achieving targets set in the past now looks uncertain, with reactors that have been built and that are ready for fueling and going into operation also on hold".[69] This is in stark contrast to the acceleration of solar and wind power in the country. The reasons for this deceleration of nuclear power are deep and, with the declining costs of renewables, likely to be enduring.

The export market for China's nuclear reactors wasn't particularly bright either. Although China signed several cooperation agreements with countries such as Cambodia, Brazil, and

64 - Ibidem.

65 - *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.

66 - C. F. Yu, "CNEC-CFHI Deal — Boosting the HTGR Or Chinese Manufacturing?", *NIW*, 9 September 2016.

67 - C. F. Yu, "HTGR May be Boosted By Industry Restructuring", *NIW*, 7 April 2017.

68 - Ibidem.

69 - Feng Hao, "Is China losing interest in nuclear power?", *China Dialogue*, 19 March 2018, see https://www.chinadialogue.net/article/show/single/en/10506-Is-China-losing-interest-in-nuclear-power-, accessed 15 May 2018.

Uganda, in the last year, there was only one concrete sales prospect—with Pakistan, also the only destination of earlier exports. One of the countries that China had been counting on was Argentina, but in May 2018, the government of Argentina announced that it "is putting on hold plans for two Chinese-supplied reactors".[70] In November 2017, the China National Nuclear Corporation and the Pakistan Atomic Energy Commission (PAEC) "signed a cooperation agreement on the construction of a HPR-1000 Hualong One reactor at the Chashma nuclear power plant".[71] The United Kingdom's Office for Nuclear Regulation continues its Generic Design Assessment (GDA) of the Hualong One design, but this process is likely to take many more years. This is a prerequisite for CGN Power's proposal to jointly develop a nuclear plant at the Bradwell site (see also U.K. Focus).

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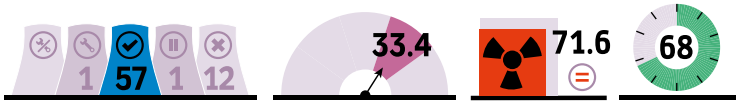


Introduction

The beginning of the End of the Reign of the Atom in France?[72]

Libération, 30 May 2018

The Pluriannual Energy Program (PPE), a planning tool introduced through the 2015 Energy Transition Law, will define the framework for the coming years to 2023 in the French energy landscape. The PPE sets the priorities of action for public authorities concerning all forms of energy generation as well as energy efficiency. It will also determine the near-term future of nuclear power in setting targets for installed capacity and the potential closure of a number of reactors. According to the French Government: "It will be completed by the end of 2018".[73] A draft was expected for July 2018 but has been delayed until September at least.

A public consultation was held that generated numerous documents, several dozen conferences and events throughout the country with some 8,000 participants. All of the main stakeholders representing state, industry, think tanks and NGOs have contributed to the debate. In total, 193 stakeholders have filed documents. A group of 400 citizens selected randomly from telephone listings met for a day to discuss and respond to a questionnaire. The results are quite remarkable. Four in five citizens of this group consider that France with the objectives of the Energy Transition Law "is behind" by international comparison. Two thirds think that the target of 50 percent nuclear should be kept for 2025 (44 percent) or 2030 (18 percent) and that there's no reason to decide before 2028 whether new European Pressurized Water Reactor (EPR) should be commissioned or not. But 71 percent thought it should be decided to close more reactors than the two Fessenheim units prior to 2028 and 62 percent are opposed to

70 - *NIW*, "Argentina Puts Newbuilds on Ice", 18 May 2018.

71 - *WNN*, "Pakistan, China agree to build Chashma 5", 23 November 2017, see http://www.world-nuclear-news.org/NN-Pakistan-China-agree-to-build-Chashma-5-2311177.html, accessed 4 May 2018.

72 - Jean-Christophe Féraud, "«L'impasse», comment l'EPR a coulé le nucléaire français", *Libération*, 30 May 2018, (in French), see http://www.liberation.fr/france/2018/05/30/l-impasse-comment-l-epr-a-coule-le-nucleaire-francais_1655363, accessed 11 August 2018.

73 - Ibidem.

the life extension of "numerous reactors" beyond 50 years. These citizens had access to practically all of the stakeholder documents.[74]

The state-controlled utility Électricité de France (EDF) seems to live in a different world and stated in its contribution to the PPE consultation that it "envisages certain closures" of nuclear reactors "starting 2029".[75] The startling suggestion simply ignores the current legislation that stipulates a reduction of the nuclear share in the French power mix to 50 percent by 2025 and the context of the entire debate. This proposal, which means the general lifetime extension to at least 50 years of the entire French fleet, also raised the stakes of a potential serious conflict between the government and "its" utility. Energy policy is usually defined by the government and executed by the utility, not the other way around. In addition, EDF suggests "a decision soon to be taken" for a new nuclear power plant, for a first startup "in 2030 or soon after".

At the same time, EDF, in its Reference Document 2017, notes the PPE, "or other energy policies in the countries where the Group operates", as risk factors, because they are "likely to lead to profound transformations or hinder the Group in its development compared to its competitors".[76]

Orano (ex-AREVA), in its contribution to the public debate, stipulates that "the number of reactor closures must not exceed the minimum threshold that allows the continued operation of the fuel cycle facilities and to maintain the French technological excellence".[77] An interesting logic: keep operating otherwise not needed power generating plants in order to provide business for otherwise not needed fuel chain facilities. Orano refers here to its plutonium activities, spent fuel reprocessing and uranium-plutonium mixed oxide (MOX) fuel fabrication. Indeed, the twenty-four 900 MW units licensed to operate with MOX fuel are also amongst the oldest reactors in France. Every MOX-absorbing unit closed, means five percent less plutonium absorption capacity. EDF is now virtually Orano's only client for the La Hague reprocessing plant and buys the vast majority of the MOX fabricated in the MELOX plant in Marcoule.

French Nuclear Power and Electricity Mix

In 2017, 57 operating reactors[78] in France produced 381.85 TWh. It is only the second time since 2009, other than 2016, to drop below 400 TWh. The drop in nuclear and low hydro production has been compensated by other thermal power plants that increased generation by 18 percent to 63 TWh.[79]

Nuclear plants provided 71.6 percent of the country's electricity, the lowest share since 1988, on the decline for the fourth year in a row and 7 percentage points below the peak year of

74 - CNDP, "Réunion de clôture", Commission Nationale du Débat Public PPE, 29 June 2018, see https://ppe.debatpublic.fr/reunion-cloture-du-debat, accessed 7 August 2018.

75 - EDF, "Cahier d'acteur n°43", Débat Public PPE, May 2018.

76 - EDF, "Reference Document 2017 including the Annual Financial Report", March 2018, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/regulated-information/reference-document/edf-ddr-2017-en.pdf, accessed 21 July 2018.

77 - Orano, "Cahier d'acteur n°65", Débat Public PPE, May 2018.

78 - All PWRs, 34 x 900 MW, 19 x 1300 MW, and 4 x 1400 MW.

79 - CGDD, "Bilan énergétique de la France métropolitaine en 2017 – Données provisoires", French Ministry for the Ecological and Inclusive Transition, April 2018.

2005 (78.5 percent). France's load factor at 67.7 percent was still poor in 2017, the fifth lowest in the world. However, it has improved from a record low of 55.6 percent in 2016, then second lowest in the world behind Argentina. The lifetime load factor has dropped below 70 percent (69.3 percent).

In WNISR2017, two reactors, Bugey-5 (880 MW) and Paluel-2 (1330 MW), were considered in LTO. Bugey-5 was shut down on 27 August 2015 for maintenance and refueling. Subsequently, an overpressure test of the containment revealed an excessive leak rate. Work went on until 15 May 2017, followed by a new leak test that confirmed the validity of the repair. Almost two years after shutdown, it was reconnected to the grid on 23 July 2017.[80] So in WNISR2018, Bugey-5 is back in the "in-operation" category.

EDF's Surprising Planning Incompetence – The Paluel-2 Case

The Paluel-2 reactor was taken off the grid for scheduled maintenance and major upgrading operations on 16 May 2015 for a planned outage until 31 January 2016.[81]

Estimate Date	Estimated Restart Date
15 May 2015	31 January 2016
1 August 2015	2 March 2016
5 November 2015	2 May 2016
28 January 2016	1 August 2016
5 March 2016	31 August 2016

Until this point, the restart date had been revised four times and was delayed by seven months. No incidents had been reported. Then, on 31 March 2016, during a replacement operation, a 22-meter-high, 465-ton steam generator was dropped on the floor inside the reactor building,[82] an accident deemed impossible in the safety case.

Since the beginning of the outage on 16 May 2015, the restart date has been delayed 19 times, including 15 times since the accident took place on 31 March 2016, leading to an additional delay of over one and a half years (see Figure 17). The chronology shows that EDF is incapable of reliably predicting grid connection even a few days ahead. Throughout all of these three-plus years of shutdown, EDF listed the event surprisingly as "planned" outage.

80 - EDF, "Bugey 5 de nouveau connectée au réseau national d'électricité", 24 July 2017, (in French), see https://www.edf.fr/groupe-edf/nos-energies/carte-de-nos-implantations-industrielles-en-france/centrale-nucleaire-du-bugey/actualites/bugey-5-de-nouveau-connectee-au-reseau-national-d-electricite, accessed 30 July 2017.

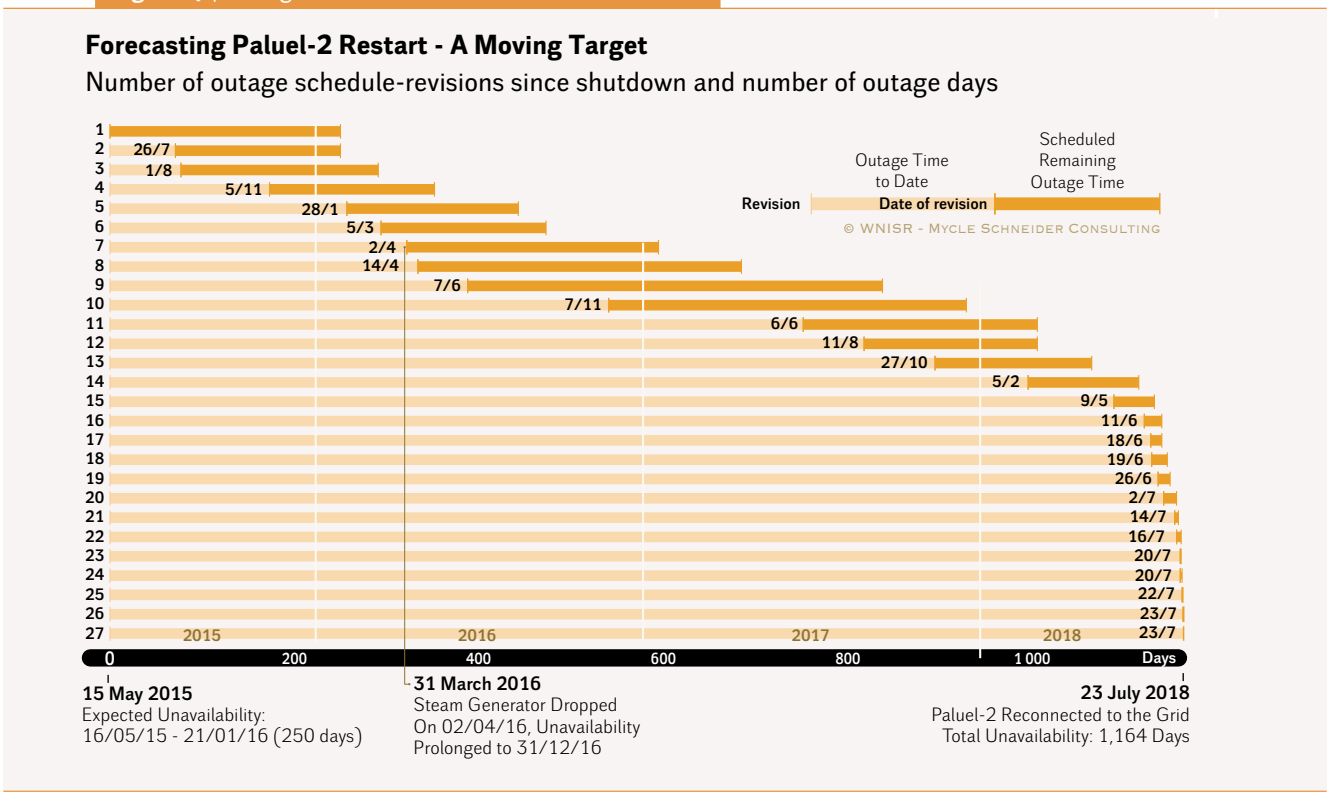
81 - All the mentioned dates are from EDF, "Liste des indisponibilités", 29 July 2018, see https://www.edf.fr/groupe-edf/qui-sommes-nous/activites/optimisation-et-trading/listes-des-indisponibilites-et-des-messages/liste-des-indisponibilites?, accessed 29 July 2018.

82 - EDF, "Accident de manutention à la centrale de Paluel", 31 March 2016, (in French), see https://www.edf.fr/groupe-edf/producteur-industriel/carte-des-implantations/centrale-nucleaire-de-paluel/actualites/accident-de-manutention-a-la-centrale-de-paluel, accessed 9 June 2017.

Only 10 hours after the reactor finally restarted on 24 July 2018[83], it was disconnected from the grid again because of an incident at a turbine. This time, the outage is labelled "failure".

The Paluel-2 case is not an exception. There are many other cases, where restart dates are revised tens of times, including from 24 hours to several months (Flamanville-1) after a minor incident.

Figure 17 | Histogram of Errant Paluel-2 Restart Predictions



Source: 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, accessed July and August 2018.

Safety and Security in Question

While Paluel-2 did not generate any power in 2017, and Bugey-5 only in the second half of the year, one of the reasons for the continuous decline in nuclear production is the snow-balling effect of ongoing investigations into irregularities in quality-control documentation and manufacturing defects (especially excessive carbon content of steel) of components produced by AREVA's Creusot[84] Forge and a Japanese AREVA sub-contractor, leading to multiple reactor shutdowns, starting in November 2016. One reactor, Fessenheim-2, shut down in June 2016, had its licensing certificate for a steam generator suspended in July 2016 by French Nuclear

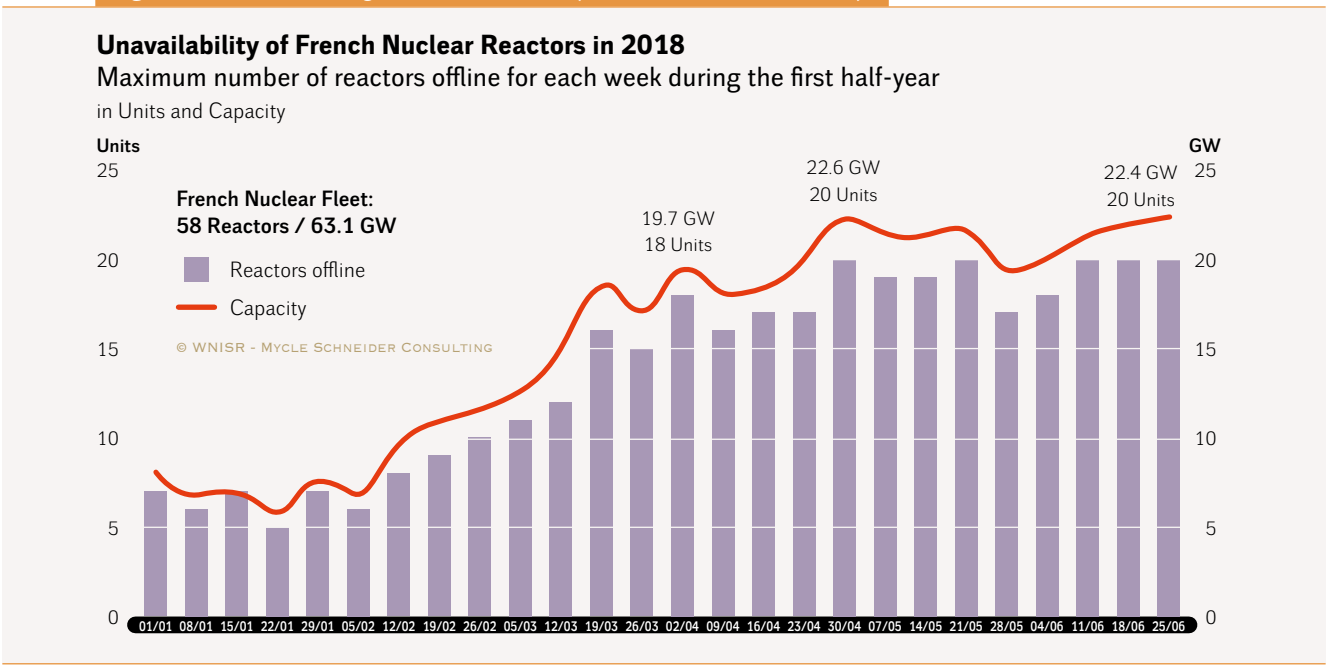
83 - As the reactor was still off-line on 1 July 2018, Paluel-2 remained in LTO in WNISR2018.

84 - 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, accessed July–August 2018.

Safety Authority (ASN). The reason for this unusual measure was that the part had not been manufactured according to technical specifications, a fact hidden by AREVA-Creusot Forge. However, following a technical investigation that stretched over 20 months, on 12 March 2018, ASN returned the licensing certificate.[85] The decision did not go well with a small minority of experts at the Permanent Expert Group advising ASN on safety issues. One of the "dissidents", Yves Marignac, Director of WISE-Paris stated: "This procedure, by its very existence, is a serious and deeply regrettable violation of the principles of exigency and responsibility which must prevail in matters of safety."[86]

In a similar case, a replacement steam generator for Gravelines-5 that was about to be installed was rejected, after the reexamination of the safety files "showed a major irregularity whose origins were unacceptable", Électricité de France (EDF) Vice President Dominique Minière, told a parliamentary committee in October 2016.[87] The reactor was shut down between April 2016 and July 2017.

Figure 18 | Reactor Outages in France in 2018 (in number of units and GWe)



Source: 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, accessed July and August 2018.

On 25 January 2018, ASN has authorized the restart of operations of Creusot Forge "under certain conditions, more particularly, the surveillance of the activities".[88] Since the industry re-

85 - ASN, "ASN has lifted its suspension of the pressure test certificate of a steam generator installed on Fessenheim NPP reactor 2", 13 March 2018, see http://www.french-nuclear-safety.fr/Information/News-releases/Fessenheim-NPP-reactor-2, accessed 12 August 2018.

86 - Yves Marignac, "Réunion du GPESPN du 27 février 2018—Déclaration d'Yves Marignac concernant l'avis sur l'aptitude au service du générateur de vapeur de Fessenheim-2", 27 February 2018.

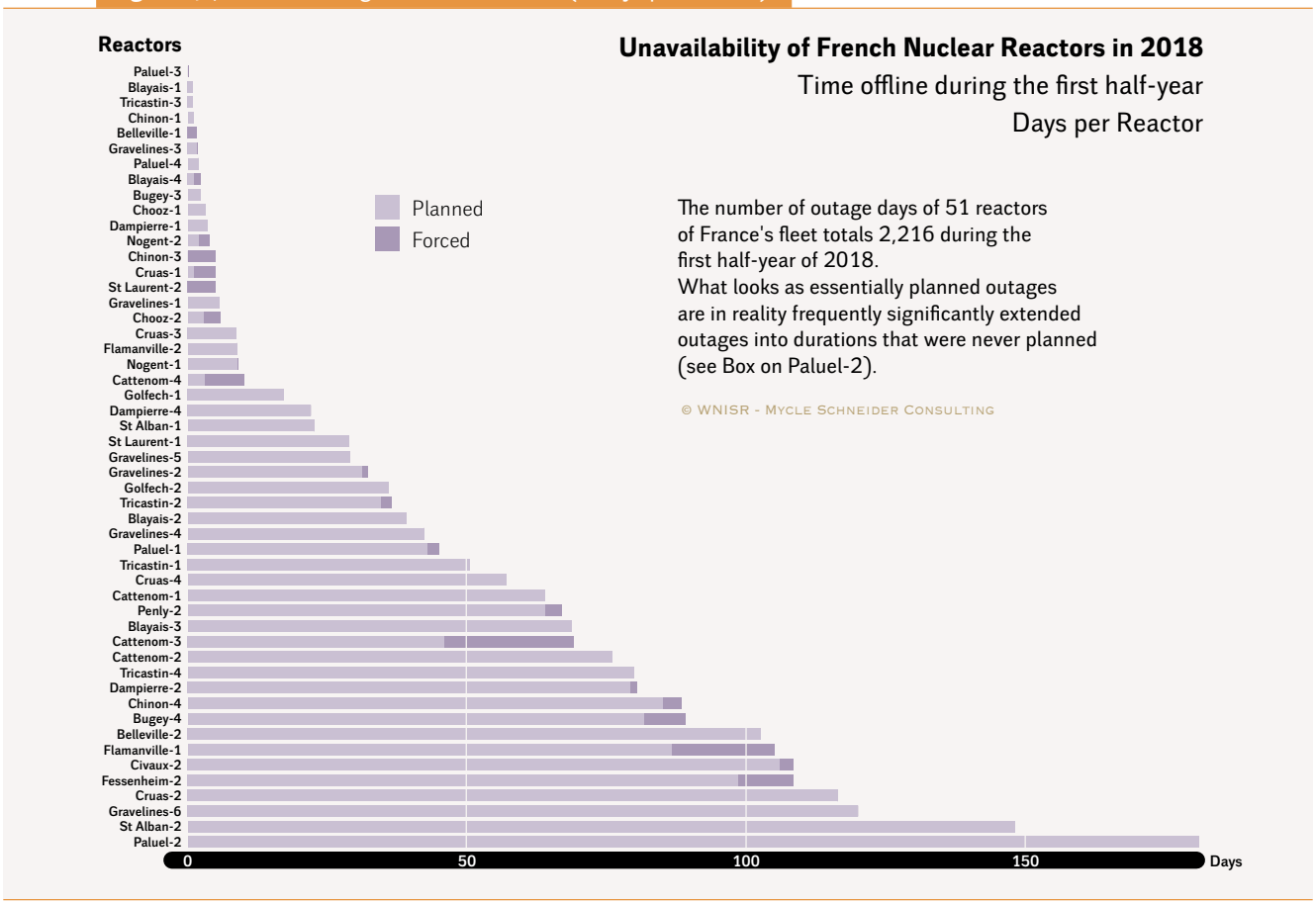
87 - Bate Felix, Geert De Clercq, "Major irregularity detected at EDF's Gravelines 5 reactor—EDF executive", *Reuters, 25 October 2016, see* http://af.reuters.com/article/commoditiesNews/idAFL8N1CV7I8, accessed 7 August 2017.

88 - ASN, "ASN considers that the steps taken by Framatome allow production to resume at the Creusot Forge plant", 25 January 2018, see http://www.french-nuclear-safety.fr/Information/News-releases/Creusot-Forge-plant-production-to-resume, accessed 22 June 2018.

structuring following the technical bankruptcy of AREVA, Creusot Forge is part of Framatome, formerly AREVA NP, absorbed by EDF.

At the beginning of 2017, EDF had assumed an annual production of 390-400 TWh with a mid-point target of 395 TWh. EDF explained the underperformance by pointing to atypical unplanned outages (-4 TWh), outage overruns (-6 TWh) and the specific case of Tricastin losses (-6 TWh). According to EDF, the outage extensions experienced in 2017 "were caused in equal measure by maintenance and operational quality issues, technical failures and project management deficiencies."[89] The problems continue in 2018, as illustrated by Figure 18 and Figure 19. In the second quarter of the year, EDF had between 13 and 20 reactors or 14–23 GW off-line (this does not include output reductions), about one third of its fleet, at any point in time.

Figure 19 | Reactor Outages in France in 2018 (in days per reactor)



Source: EDF, "List of outages", op.cit.

The Tricastin losses mentioned above are due to an unprecedented move by the regulator. On 27 September 2017, "ASN required that EDF temporarily shut down the four reactors of the Tricastin nuclear power plant as rapidly as possible", because of the "risk of failure of a part of the embankment of the Donzère-Mondragon canal with regard to the most severe earthquakes studied in the nuclear safety case."[90] ASN's technical backup Institute for Radiation Protection

89 - EDF, "Annual Results 2017", 16 February 2018.

90 - ASN, "Insufficient seismic resistance of a part of the Donzère-Mondragon canal embankment: ASN imposes temporary shutdown of the Tricastin nuclear power plant", 28 September 2017, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-imposes-temporary-shutdown-of-the-Tricastin-nuclear-power-plant, accessed 15 July 2018.

and Nuclear Safety (IRSN) released a briefing that stated that the plant had not been designed to withstand flooding from the canal. Such an event would "lead to the total loss of cooling of the fuel in the core and in the spent fuel pool of every reactor leading to the meltdown of that fuel".[91]

It took until 5 December 2017 for ASN to accept the embankment repair work carried out by EDF and grant permission for restart of the Tricastin reactors.[92]

The Tricastin episode raises the question, how seven years after 3/11 and the subsequent stress tests, it took such a sudden, dramatic measure to correct an earthquake risk related situation that had originally been flagged ten years earlier.

The Tricastin case is only one amongst a long list of safety related issues in France that raised concerns amongst experts. A series of unexplained drone overflights, several intrusions into nuclear power plants by Greenpeace activists and a high-profile 104-minute *ARTE* television documentary, first broadcasted in December 2017,[93] added serious nuclear security concerns to the picture. In January 2018, the National Assembly set up an Inquiry Committee into nuclear safety and security. The Committee released its report on 5 July 2018.[94] The first of 33 recommendations stipulates:

> Promoting the presence of non-institutional experts amongst organizations like ASN, IRSN, ANDRA [National Radioactive Waste Management Office] or HCSTISN [High Commission on the Transparency and Information on Nuclear Safety] in order to reduce 'l'entre-soi' of the technicians illustrated during the hearings. Remunerate the participation of independent experts in these instances.

The report also recommends enlarging the responsibilities of the nuclear safety regulator ASN to nuclear security, as is the case in most nuclear countries. Another recommendation stipulates to modify the classification of generic anomalies and each of the facilities affected as separate event, rather than to account just for one generic incident. The report also recommends "envisaging each time possible dry storage of spent fuel" rather than pool storage and assessing the "pursuit or not" of spent fuel reprocessing. The MPs would also like to see the publication of a "provisional plan of the reactors to be decommissioned, with the estimated costs and dates".

For many years, France was Europe's largest electricity exporter, and after a drop in the late 2000s, 61.7 TWh were exported net in 2015, a trade surplus approaching previous levels. But in 2016, net exports dropped by 36.6 percent to 39.1 TWh, the lowest level since 2010. While Germany's 2016 net power exports hit a new record at 53.7 TWh. For the first time, Germany

91 - IRSN, "Protection du site du Tricastin contre les risques d'inondation—Comportement des digues du canal de Donzère-Mondragon en cas de séisme", 28 September 2017, (in French), see http://www.irsn.fr/FR/Actualites_presse/Actualites/Documents/IRSN_NI-Tricastin-Digues-canal-donzere-seisme_20170928.pdf, accessed 15 July 2018.

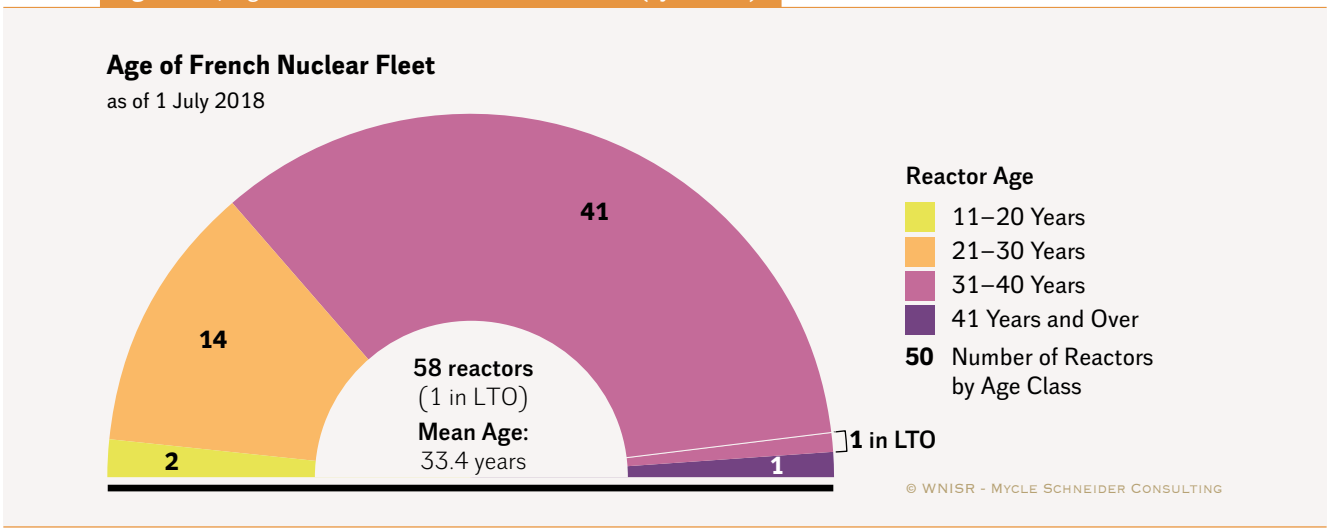
92 - ASN, "ASN allows restart of the reactors of the Tricastin nuclear power plant (NPP)", 5 December 2017, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-allows-restart-of-the-reactors-of-the-Tricastin-nuclear-power-plant-NPP, accessed 22 June 2018.

93 - *ARTE*, "Nuclear Security: The Big Lie", 2018, see http://sales.arte.tv/fiche/6285/SECURITE_NUCLEAIRE___LE_GRAND_MENSONGE__2X52,_accessed 15 July 2018. Mycle Schneider was a consultant to the project.

94 - Barbara Pompili, "Rapport d'enquête de Mme Barbara Pompili sur la sûreté et la sécurité des installations nucléaires", French National Assembly, 28 June 2018, (in French), see http://www.assemblee-nationale.fr/15/rap-enq/r1122.asp, accessed 15 July 2018.

overtook France and became the biggest net power exporter in Europe.[95] In 2017, this trend was reinforced with France's net exports shrinking again to 38 TWh net,[96] while Germany's net exports increased again to some 55 TWh,[97] with France being the second largest net importer from Germany with 13.7 TWh.[98] In January 2018, France imported just under 1 TWh net, "a level that had never been reached", according to RTE.[99] Two capacity records were also attained, when France exported net 17 GW on 30 March 2017 and imported net 10.6 GW of power on 2 December 2017.

Figure 20 | Age Distribution of French Nuclear Fleet (by Decade)



Sources: WNISR, with IAEA-PRIS, 2018

The average age of France's 58 power reactors is 33.4 years by mid-2018 (see Figure 20). In the absence of new reactor commissioning and any shutdown, the fleet is aging by one year every year. Questions are being raised about the investment needed to enable them to continue operating, as aging reactors increasingly need parts to be replaced. The first two reactors, Fessenheim1 and 2, have passed the 40-year mark in 2017. Their closure was part of the previous government's commitments. The commitment has been confirmed under the Macron Presidency, which promises to do that "when the Flamanville EPR starts up"[100]—but this deadline has been constantly pushed back.

Life extension beyond 40 years of some reactors—41 operating units (plus one in LTO) are now over 31 years old—would require significant additional upgrades. ASN—quite different from regulators, for example, in the U.S. that only request the safety standard at commissio-

95 - AGEB, "Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern", Arbeitsgruppe Energiebilanzen, February 2017, (in German), see http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=20170207_brd_stromerzeugung1990-2016.pdf, accessed 23 June 2017.

96 - RTE, "Mon bilan électrique 2017", 2018.

97 - Sibylle Wilke, "Stromerzeugung erneuerbar und konventionell", Umweltbundesamt, German Environment Agency, 15 March 2018, (in German), see http://www.umweltbundesamt.de/daten/energie/stromerzeugung-erneuerbar-konventionell, accessed 17 July 2018. Provisional figures for German net exports vary between "over 54 TWh" and over 60 TWh ; see Agora Energiewende, January 2018 hereunder, and the chapter Focus Germany.

98 - Agora Energiewende, "Die Energiewende im Stromsektor: Stand der Dinge 2017", January 2018.

99 - RTE, "Bilan électrique 2017", 2018.

100 - Gouvernement français, "Compte rendu du Conseil des ministres du 7 novembre 2017—Trajectoire d'évolution de l'énergie électrique ", 7 November 2017, (in French), see https://www.gouvernement.fr/conseil-des-ministres/2017-11-07/trajectoire-d-evolution-de-l-energie-electrique, accessed 22 June 2018.

ning—requires further life extension to be contingent on a safety level "as close as possible" to evolutionary reactors like the EPR. Also, relicensing will be subject to public inquiries reactor by reactor.

Operating costs have increased substantially over the past years. Investments for life extensions will need to be balanced against the already 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, successful competitors, and the energy efficiency and renewable energy production targets set at both, the EU and the French levels. EDF claims that the power generating costs for existing reactors would be €32/MWh (US$38/MWh), including nuclear operating and maintenance costs (€22/MWh incl. fuel at €5/MWh) and all anticipated upgrading costs for plant life extension to 50 years (10 €/MWh) remain more economic than "any new alternative".[101] However, there are serious questions about these numbers. Michèle Pappalardo, Ecology Minister Nicolas Hulot's Chief of Staff and former senior representative of the Court of Accounts, remarked during the hearings of the Inquiry Committee 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.[102]

EDF lost 1.1 million customers in 2017, almost 100,000 every month.[103] And with the recent takeover of big player Direct Energie by Total, the competition will only get harder.

It remains plausible that EDF will attempt to extend lifetimes of some units, while others might be closed even prior to reaching the 40-year age limit. Any decision remains suspended to the revision of the Pluriannual Energy Plan (PPE) and the nuclear safety authority's generic judgement over lifetime extensions (probably 2019), followed by a case-by-case procedure.

EDF has stated that it does not intend to shut down *any* reactors prior to 2029, beyond the two Fessenheim units. Some scenarios, elaborated by its subsidiary RTE, suggest a formidable increase in electricity exports to justify the preservation of the entire fleet.[104] Two of five scenarios ("Ampère" and "Volt") assume net exports exceeding 100 TWh as soon as 2025, and 135 TWh and 159 TWh respectively by 2025. But the assumption of such an additional export market for EDF is not justified by current trends. German power companies are already taking some of that market, as they undercut French prices. And in a structural overcapacity situation, like throughout Europe, with still continuously increasing renewable energy capacities, competition will only increase. In fact, it seems impossible to exclude today a scenario, where a significant number of reactors will be shut down, as they cannot compete in the market (just as is already happening in the U.S).

Current legislation still calls for a reduction from roughly 75 to 50 percent nuclear share in the electricity production mix by 2025. The current government considers this target unrealistic

101 - EDF, "Le parc nucléaire en exploitation en France : Exploitation, maintenance et Grand Carénage", 11 January 2018.

102 - 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.

103 - Barbara Pompili, "Rapport d'enquête sur la sûreté et la sécurité des installations nucléaires—N°1122 tome I", French National Assembly, 28 June 2018, (in French), see http://www.assemblee-nationale.fr/15/rap-enq/r1122.asp, accessed 15 July 2018.

104 - RTE, "Bilan prévisionnel : cinq scénarios possibles de transition énergétique", 7 November 2017, (in French), see https://www.rte-france.com/fr/actualite/bilan-previsionnel-cinq-scenarios-possibles-de-transition-energetique, accessed 19 July 2018.

and wishes to push it back to 2030 or even further. However, Nicholas Hulot, the minister in charge of the energy transition, wishes to define a reactor-by-reactor closure scheme to concretely determine, how to get down to the 50 percent level: "By the end of the PPE, we will have a quite precise order of magnitude of the number of reactors to be shut down, a calendar and a schedule."[105]

There are other reasons to put the brakes on a nuclear phaseout in France. Emmanuel Macron said, in an interview a few days before taking office on 14 May 2017, when asked why he would not right now fix a target for a nuclear phaseout and a 100 percent renewables-based system:

> If I did that, the same second, I would worsen the problems of Areva and EDF, who is the largest bond issuer in Europe. The second you have someone in charge saying: 'My objective is the death of her [EDF's] business', it's over. Nobody will lend her anymore.

The Ongoing Flamanville-3 EPR Saga

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. The project has been plagued with detailed-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. In fact, these problems never stopped. In April 2018, it was discovered that the main welds in the secondary steam system did not conform with the technical specifications and repair work might again cause "a delay of several months to the start-up of the Flamanville 3 European Pressurized Water Reactor (EPR) reactor."[106]

The Flamanville-3 project—until the latest discovery—was expected to start generating power in May 2019, reaching full capacity in November 2019.[107] The official cost estimate for Flamanville-3 stood at €8.5 billion (US$11.6 billion) as of December 2012.[108] In its annual report 2015, EDF updated the figure to €10.5 billion (US$12.3 billion)[109], and has not updated it since. The figure is equivalent to the latest estimate for the Olkiluoto-3 EPR project in Finland, and 3.2 times the estimate at construction start. EDF's President Bernard Lévy stated on 28 July 2017: "We are in line with the schedule and the budget that we announced in 2015."[110] In fact, the road map presented by EDF in September 2015[111] scheduled "fuel loading and startup" for the fourth quarter 2018, but omitted to provide a grid-connection date, which was given

105 - Luc Chaillot, "Nucléaire : un calendrier de fermeture avant fin 2018", *Le Républicain Lorrain*, 20 March 2018, (in French), see https://www.republicain-lorrain.fr/france-monde/2018/03/20/nucleaire-un-calendrier-de-fermeture-avant-fin-2018, accessed 22 July 2018.

106 - 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.

107 - Bate Felix, Benjamin Mallet, "L'EPR de Flamanville attendu à pleine puissance en novembre 2019", *Reuters*, 11 July 2017, (in French), see http://fr.reuters.com/article/businessNews/idFRKBN19W21B-OFRBS, accessed 31 July 2017.

108 - Ludovic Dupin, "EDF a évité le pire sur l'EPR de Flamanville", *Usine Nouvelle*, 7 December 2012, (in French), see http://www.usinenouvelle.com/article/edf-a-evite-le-pire-sur-l-epr-de-flamanville.N187560, accessed 18 June 2016.

109 - EDF, "2015 Management Report—Group Results", 13 May 2016.

110 - EDF, "Half-Year Results 2017", Conference call Jean-Bernard Lévy with Analysts and Investors, 28 July 2017.

111 - Jean-Bernard Lévy, Xavier Ursat, "Conférence de Presse", EDF, Press Conference, 3 September 2015, (in French), see https://www.edf.fr/sites/default/files/Finance/EDF_Presentation_EPR_Flamanville_03_09_2015.pdf, accessed 17 March 2017.

only in 2017 as the second quarter of 2019. De facto, the current planning represents at least six months delay in the construction schedule since 2015 (not counting potential additional delays after the steam-system problem discovery).

In April 2015, the French Nuclear Safety Authority (ASN) revealed that the bottom piece and the lid of the FL3 pressure vessel had "very serious" defects.[112] Chemical and mechanical tests "revealed the presence of a zone in which there was a high carbon concentration, leading to lower than expected mechanical toughness values".[113] Both pieces were fabricated and assembled by AREVA in France, while the center piece was forged by Japan Steel Works (JSW) in Japan. ASN stated then that the same fabrication procedure by AREVA's Creusot Forge was applied to "certain calottes" (also called bottom heads and closure heads) of the two pressure vessels made for the two EPRs under construction at Taishan in China, while the EPR under construction in Finland was entirely manufactured in Japan. It remains unclear, which of the two bottoms and two lids have been manufactured by Creusot Forge, but likely at least the ones for Taishan-1, while, according to AREVA[114] and media reports[115], the pressure vessel for Taishan-2 has been manufactured by Chinese company Dongfang Electric Corporation (DEC). However, no specific mention is made of the vessel bottoms and lids. Taishan-1 was connected to the grid on 29 June 2018, with no mention whatsoever of the carbon enclosure issue.

AREVA's challenge was to prove that, although clearly below technical specifications, the EPR pressure vessels could withstand any major transient. After a lengthy and controversial re-qualification procedure (see WNISR2017 for details), ASN released its official judgement on the issue considering the "mechanical characteristics" of vessel cover and bottom "adequate". ASN considers however that EDF "must implement additional periodic inspections to ensure that no flaws appear subsequently". As the technical feasibility at this point cannot be considered established for the cover, "ASN therefore considers that the use of the closure head must be limited in time" and as a new closure head could be available by 2024, the current piece "shall not be operated beyond that date".[116]

In July 2018, cost and schedule were revised again. "The EDF group has therefore adjusted the Flamanville EPR schedule and construction costs accordingly. The loading of nuclear fuel is now scheduled for the 4th quarter in 2019 and the target construction costs have been revised from €10.5 billion to €10.9 billion", EDF declared in a statement.[117]

The reactor is now at least 7.5 years behind schedule.

112 - Ludovic Dupin, "Le cri d'alarme de l'ASN sur le nucléaire français", *Usine Nouvelle*, 20 January 2016, (in French) see http://www.usinenouvelle.com/article/le-cri-d-alarme-de-l-asn-sur-le-nucleaire-francais.N374729, accessed 11 June 2016.

113 - ASN, "Flamanville EPR reactor vessel manufacturing anomalies", Press Release, 7 April 2015, see http://www.french-nuclear-safety.fr/Information/News-releases/Flamanville-EPR-reactor-vessel-manufacturing-anomalies, accessed 14 August 2017.

114 - AREVA, "Taishan 1&2 - China—AREVA Supply Chain", undated, see http://www.areva.com/EN/operations-2404/china-taishan-12.html - tab=tab5, accessed 14 August 2017.

115 - *FactWire*, "Made in China: critical component of Taishan nuclear plant manufactured in Guangzhou", 26 May 2016, see https://www.factwire.org/single-post/2016/05/27/Made-in-China-critical-component-of-Taishan-nuclear-plant-manufactured-in-Guangzhou, accessed 2 July 2016.

116 - ASN, "ASN presents its position regarding the Flamanville EPR reactor vessel anomaly", Press Release, 28 June 2017, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-presents-its-position-regarding-the-Flamanville-EPR-reactor-vessel-anomaly, accessed 31 July 2017.

117 - 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.

Fallout from the Creusot Forge Affair

Meanwhile, the finding of carbon segregations in the pressure of Flamanville-3 had raised concerns about the possibility that other components could have been fabricated below technical specifications due to poor quality processes at Creusot Forge.[118]

Media reports revealed in March 2017 that ASN had warned AREVA and EDF as early as 2005-06 about quality issues at Creusot Forge. At the time, ASN President André-Claude Lacoste stated: "Your supplier has big problems, either replace it or buy it!"[119] AREVA chose to buy Creusot Forge in 2006. However, this did not solve the issue.

It remains unclear why it took the detection of the manufacturing problems with the EPR pressure vessel for ASN to request an audit of the Creusot Forge plant, a decade after the first major issues had been identified. On 25 April 2016, AREVA informed ASN that "irregularities in the manufacturing checks", the quality-control procedures, were detected at about 400 pieces fabricated since 1969, about 50 of which would be installed in the French currently operating reactor fleet. The "irregularities" included "inconsistencies, modifications or omissions in the production files, concerning manufacturing parameters or test results".[120]

The most serious regulatory violation led ASN to withdraw the certificate of a replacement steam generator introduced in Fessenheim-2 in 2012 –because the forging process of its central part was not compliant to qualified methods, and this was covered in the documentation submitted to ASN and EDF, leaving the reactor shutdown between June 2016[121] and April 2018.

According to EDF, in total, it has detected 1,775 "anomalies" in parts that were integrated into 46 reactors.[122]

In September 2017, EDF transmitted to ASN its analysis on parts concerning a first series of 12 reactors that were to be restarted after outages before the end of the year. On 30 November 2017, ASN granted permission to use the parts. On 17 July 2018, EDF sent its assessment of the manufacturing dossiers of 1,142 parts to ASN concerning a total of 46 reactors. Examination of these dossiers by ASN is expected to last until the end of 2018.

The information released on EDF's website covers, however, only 42 reactors and there is no information on the nature of the 1,142 affected parts. EDF found a total of 1,775 violations of regulatory or contractual requirements, ranging from 16 to 55 per reactor, plus 449 violations of the manufacturer's internal guidelines. There are a range of requirements *per part*. About half

118 - The regulation on pressurised components of nuclear facilities changed in 2005. In particular, it now requires that mechanical properties should be verified in every areas of the components, instead of only the most sensitive areas before.

119 - Sylvain Tronchet, "Cuve de l'EPR de Flamanville : l'incroyable légèreté d'Areva et EDF", *France Inter*, 31 March 2017, (in French), see https://www.franceinter.fr/sciences/cuve-de-l-epr-de-flamanville-l-incroyable-legerete-d-areva-et-edf, accessed 15 August 2017.

120 - ASN, "AREVA has informed ASN of irregularities concerning components manufactured in its Creusot Forge plant", 4 May 2016, see http://www.french-nuclear-safety.fr/Information/News-releases/Irregularities-concerning-components-manufactured-in-its-Creusot-Forge-plant, accessed 14 August 2017.

121 - Pierre-Franck Chevet, "Décision n° CODEP-CLG-2016-02945 du 18 juillet 2016 du Président de l'Autorité de sûreté nucléaire suspendant le certificat d'épreuve du générateur de vapeur n° 335 fabriqué par AREVA NP", ASN, République Française, 18 July 2016, (in French), see https://www.asn.fr/content/download/105596/795168/version/1/file/Décision n° CODEP-CLG-2016-02945 du 18 juillet 2016.pdf, accessed 10 August 2017.

122 - These numbers and the following three paragraphs from EDF, "Dossiers de fabrication", 17 July 2018, (in French), see https://www.edf.fr/groupe-edf/nos-energies/nucleaire/segregation-carbone-et-dossiers-de-fabrication-creusot-forge/dossiers-de-fabrication, accessed 20 July 2018.

of the assessed findings relate to the thermal treatment in the manufacturing process, while the other half is related to the chemical values or deviations during the testing phases. EDF claims that none of these irregularities prevents the parts to function "in complete safety" (en toute sûreté).

In September 2016, AREVA took the decision to review all of some 6,000 manufacturing files for nuclear components from Creusot Forge. About one third were delivered to EDF, of which about 1,600 are installed in operating reactors. There is no such information available concerning the 4,000 manufacturing files that concern clients other than EDF.

ASN's own inspections at the Creusot Forge plant in January 2016 also revealed that high carbon concentrations had been found in the calottes for the FL3 pressurizer, following a request for additional tests by AREVA NP (now Framatome) dating as early as December 2008. Neither the request for these tests nor their results had been communicated to ASN.[123]

ASN had also requested EDF to review the safety files of equipment that could present undetected carbon segregations, although fabricated according to specifications of the time. A problem of particularly high carbon content—up to 50 percent higher than the limit in technical specifications—was found in the channel head steel of 20 steam generators fabricated at Creusot Forge and 26 by AREVA sub-contractor Japan Casting and Forging Corporation (JCFC), that had not been reported by the manufacturer. This led to the provisional shutdown for inspections of a dozen reactors in France in the winter 2016-17. ASN had considered the potential risk of failure high enough to order EDF to carry out inspections within three months.

Industry Restructuring

The capital increase of Orano (ex-AREVA, similar to old-COGEMA) of €3 billion (US$3.5 billion) was completed mid-2017, with €2.5 billion (US$2.9 billion) to come from the French State and €0.5 billion (US$0,6 billion) from the Japanese consortia Japan Nuclear Fuel Limited (JNFL) and Mitsubishi Heavy Industries LTD (MHI). Most of the key financial indicators remained on the negative side in 2017, as revenues dropped by seven percent, EBITDA[124] plunged by over 29 percent, net cashflow from company operations was negative by over €1 billion (US$1.2 billion), 16.5 percent worse than the year before.[125]

As of the end of 2017, EDF acquired 75.5 percent of the capital of Framatome (ex-AREVA-NP). Japanese MHI and French engineering firm Assystem took equity stakes of 19.5 percent and five percent respectively. The contracts linked to Finnish EPR project at Olkiluoto as well as "certain contracts relating to components forged in Le Creusot plant" remains with AREVA SA, sort of empty shell with a few serious liabilities, held by the French government (see Figure 21).[126]

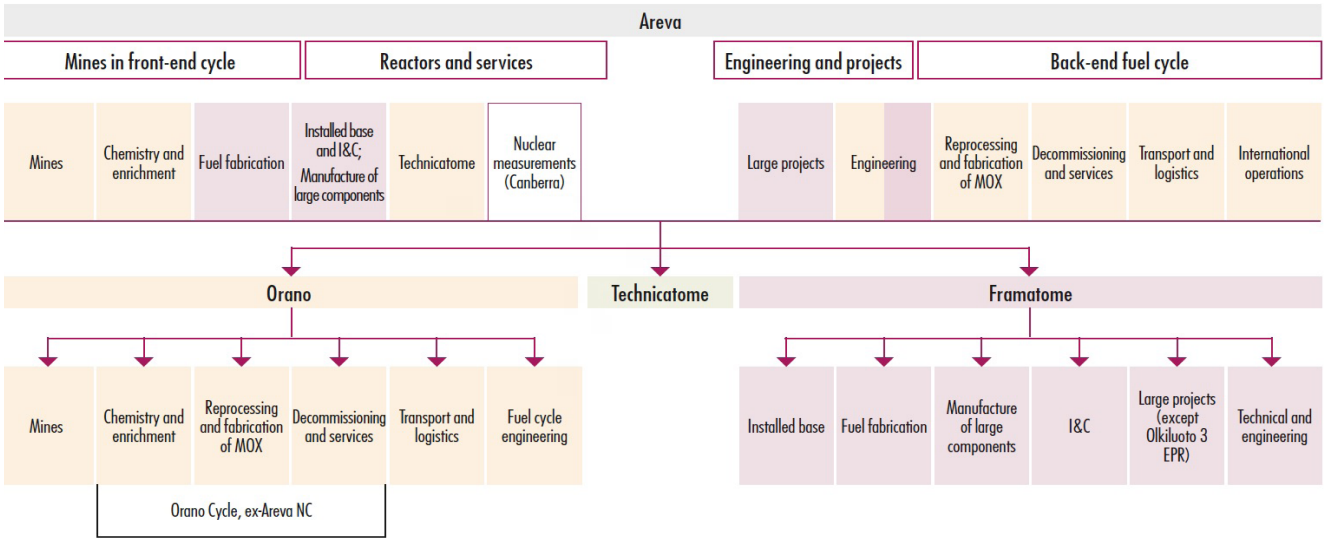
123 - ASN, Letter to the Director General of AREVA NP, 9 May 2016.

124 - Earnings before interest, taxes, depreciation and amortization

125 - Orano, "Annual results for 2017", 29 March 2018.

126 - These and following unreferenced numbers from EDF, "Reference Document 2017", March 2018, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/regulated-information/reference-document/edf-ddr-2017-en.pdf, accessed 21 July 2018.

Figure 21 | The Dismantling of AREVA



Source: ASN, Annual Report 2017, 2018

Following a €4 billion (US$4.6 billion) capital increase and €4.35 billion (US$5 billion) in asset disposals, by mid-2017, net debt had declined to €31.3 billion (US$36.8 billion).[127] But it did not last. As of the end of 2017, EDF had an official net debt of €33 billion (US$39 billion), in spite of doubling asset disposals to €8.1 billion (US$9.7 billion).

Investment levels remain substantial with €16 billion (US$19 billion) in 2017, including the Framatome purchase for €1.9 billion (US$2.3 billion) and "British Nuclear New-build", mainly Hinkley Point C, for €1.2 billion (US$1.4 billion) (see also *WNISR2016* for "The Hinkley Point C Saga – A French Perspective").

While EDF had already spent €3 billion (US$3.6 billion) prior to the signature of the contracts for 2017 EDF announced that "firm commitments" in connection with the "acquisition of tangible assets for the building of Hinkley Point C have been formalized under contractual agreements for an amount of €2.7 billion [US$3 billion]".[128] EDF's Reference Document 2016 contains under the section "Specific risks related to the Group's nuclear activities" a risk factor entitled "Construction of EPRs may encounter problems meeting the implementation schedule or the budgetary envelope or not be completed".[129] A few months into 2017, EDF's CEO admitted:

> Project completion costs are now estimated at £19.6 billion$_{2015}$ [US$29 billion$_{2015}$]. This is an increase of £1.5 billion$_{2015}$ [US$2.2 billion$_{2015}$], compared to previous valuations. The project review, on top of this, identified a potential 15-month deferral of the delivery date of Unit 1 and a potential nine-month deferral for Unit 2. [130]

127 - EDF, "Half-Year Results 2017", 28 July 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/investors-shareholders/financial-information/regulated-information/financial-results, accessed 15 August 2017.

128 - Ibidem.

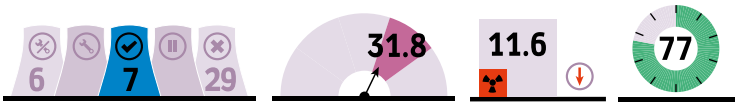
129 - Ibidem.

130 - 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 14 August 2017.

The fact that a "not be completed" risk assumption is quite realistic has been illustrated by 90 abandoned nuclear construction sites up to 1 January 2017, documented in the WNISR's Global Nuclear Power Database[131]. The latest case to be added is the abandoning of the two AP1000 reactors under construction at the Summer site in South Carolina, U.S. (see United States Focus).

EDF has committed to additional investment efforts, including for the development of new reactor designs. But it is "renewables and services activities", that today constitute its "key growth drivers", according to EDF's CEO.[132] EDF's total net installed renewables capacity (excluding large hydro) in the world remains modest with 9.4 GW producing 3 percent of EDF's electricity. However, in December 2017, the group announced a "solar plan" with a target of 30 GW installed over a period of 15 years between 2020 and 2035 for an investment of €25 billion (US$29.5 billion). To put this figure into perspective, China added 53 GW in 2017.

GERMANY FOCUS



Germany's remaining eight nuclear reactors generated 72.2 TWh net in 2017, a 10 percent drop over the previous year and 50.5 percent less than in their record year 2001. They provided 11.6 percent of Germany's electricity generation, little more than one third of the historic maximum of 30.8 percent two decades ago in 1997. One more reactor (Gundremmingen-B) was shut down at the end of 2017, according to the nuclear phase-out legislation (see Table 3 for details), which leaves Germany with seven reactors in 2018. While the load factor dropped by 10.5 percent to 77 percent, the lifetime load factor remains at 86 percent the third highest in the world (behind Romania and Finland). Three German reactors are amongst the best ten lifetime load factors. All eight units that generated power in 2017 are in the Top Ten lifetime electricity generators in the world, holding positions one to six. (Only two U.S. reactors, Peach Bottom-2 and -3, made it into the Top Ten besides the German units).[133]

Germany decided immediately after 3/11 to shut down eight of the oldest of its 17 operating reactors and to phase out the remaining nine until 2022. 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 increased power output by a record 28.2 TWh in 2017 and contributed 218 TWh (+15 percent) to the gross national electricity generation, three times as much as nuclear energy. Hard-coal based generation dropped by 17.5 percent and lignite by 1.4 percent, while natural gas increased its share by 6.4 percent. Renewables were again by far the largest contributor to

131 - WNISR/Visionscarto/*Bulletin of the Atomic Scientists*, "The Global Nuclear Power Database", see http://thebulletin.org/global-nuclear-power-database.

132 - EDF, "Half-Year Results 2017", Conference call Jean-Bernard Lévy with Analysts and Investors, 28 July 2017.

133 - *NEI*, "Load factors to end December 2017", May 2018.

the power mix and supplied 36.2 percent of gross generation—more than lignite (23.1 percent), hard coal (17.2 percent) and natural gas (12.4 percent).[134]

Installed wind generating capacity grew by 6.3 GW to 55.9 GW in 2017, while solar added a modest 1.7 GW of capacity to reach 42.4 GW.[135] The cumulated installed solar capacity can be compared to French EDF's 2035-target of 30 GW.

In 2016, Germany's net power exports hit a new record at 53.7 TWh, and as the French electricity trade surplus plunged from 61.7 TWh in 2015 to 39.1 TWh in 2016 (-37 percent), for the first time, Germany became the biggest net exporter in Europe. It is intriguing to see that 2016 apparently was not an exceptional year, as Germany continued to increase its trade surplus to about 55 TWh,[136] while France's net exports shrank again to 38 TWh.

> *"Germany continued to increase its trade surplus to about 55 TWh, while France's net exports shrank again to 38 TWh"*

Figure 22 summarizes the main developments of the German power system between 2010—the last year prior to the post-3/11 shutdown of the eight oldest nuclear power plants—and 2017. It shows that the remarkable increase of renewable electricity generation (+113 TWh) and the reduction in domestic consumption (-16 TWh) were far more than sufficient to compensate for the reduction of nuclear generation (64.3 TWh), enabling also a reduction in power generation from fossil fuels (-28.4 TWh) and a threefold increase in net exports. Within the fossil fuel segment, natural gas is lower than in 2010, but has increased constantly since 2014 (+24.4 TWh), compensating the constant, significant decline of power generated from hard coal from 117 TWh in 2010 to 92.6 TWh in 2017 (-24.4 TWh or -21 percent). The black spot in the balance remains the fact that, while lignite use—the most polluting way to generate power—has continuously declined over the past five years, remains slightly above the 2010 level. This might change. In the first half of 2018, renewables' generation outpaced, for the first time, hard coal and lignite generation combined with an estimated 118 TWh versus 114 TWh respectively.[137]

Greenhouse gas emissions from the power sector dropped again by 4.4 percent in 2017, while carbon intensity decreased from 527 gCO_2/kWh to 500 gCO_2/kWh.[138]

134 - Federal Ministry for Economic Affairs and Energy, "Development of Renewable Energy Sources in Germany in 2017", March 2018.

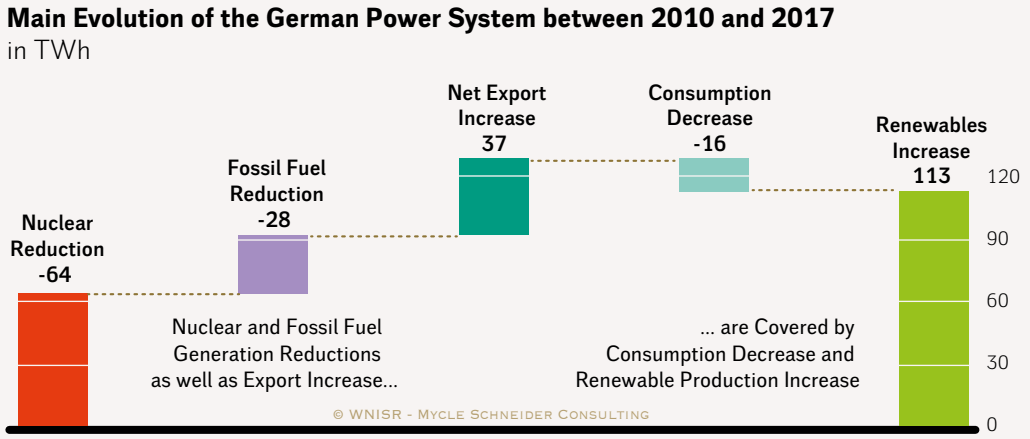
135 - Ibidem.

136 - AGEB, "Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern", Working Group on Energy Balances, February 2018, (in German), see https://ag-energiebilanzen.de/index.php?article_id=29&fileName=20171221_brd_stromerzeugung1990-2017.pdf, accessed 23 July 2018.

137 - BDEW, "Erneuerbare überholen erstmals Braun- und Steinkohle bei der Stromerzeugung", Bundesverband der Energie- und Wasserwirtschaft e.V., 10 July 2018, (in German), see http://www.bdew.de/presse/presseinformationen/erneuerbare-ueberholen-erstmals-braun-und-steinkohle-bei-der-stromerzeugung/, accessed 11 July 2018.

138 - Agora Energiewende, "Die Energiewende im Stromsektor: Stand der Dinge 2017—Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2018", January 2018, see https://www.agora-energiewende.de/fileadmin/Projekte/2018/Jahresauswertung_2017/Agora_Jahresauswertung-2017.pdf, accessed 22 June 2018.

Figure 22 | Main Developments of the German Power System Between 2010 and 2017



Source: WNISR based on AGEB, 2018[139]

Table 3 | 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; IAEA-PRIS 2017

Notes pertaining to the table

PWR=Pressurized Water Reactor; BWR=Boiling Water Reactor; RWE= RWE Power AG

a - Vattenfall 66,67%, E.ON 33,33%

b - Vattenfall 50%, E.ON 50%.

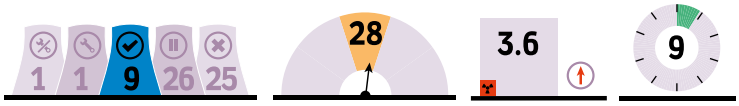
c- RWE 75%, E.ON 25%.

d - E.ON 80%, Vattenfall 20%.

e - RWE 87,5%, E.ON 12,5%.

139 - AGEB, "Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern", Working Group on Energy Balances, February 2018, (in German), see https://ag-energiebilanzen.de/index.php?article_id=29&fileName=20171221_brd_stromerzeugung1990-2017.pdf, accessed 21 July 2018.

JAPAN FOCUS



Four reactors have restarted in Japan since 1 July 2017, bringing the total number in operational status to nine. The four reactors to restart in the past year were Ohi-3 and -4 and Genkai-3 and -4, joining the Sendai-1 and -2 reactors, which resumed operation in 2015,[140] the Ikata-3 reactor, which restarted in 2016, Takahama-4 on 22 May 2017[141] and Takahama-3 on 9 June 2017.[142]

Three Pressurized Water Reactors (PWRs) and the Prototype Fast Breeder Reactor (PFBR) Monju were officially declared for decommissioning in the last year, bringing to 16 the number of reactors officially permanently shut down since the Fukushima Daiichi accident began in March 2011.

This means that as of 1 July 2018, 26 reactors remain in Long-Term Outage (LTO) since none of these have generated electricity during recent years. WNISR considers that all 10 Fukushima units are closed and will never restart. (See Figure 23 and Annex 2 for a detailed overview of the Japanese Reactor Program).

In 2017, nuclear power production was 29 TWh, contributing 3.6 percent of the nation's annual output; this compares with 17.5 TWh in 2016, supplying 2.2 percent of the nation's annual output. This is the largest share of nuclear generated electricity in Japan since 2011 (18 percent), compared with 29 percent in 2010, and the historic maximum of 36 percent in 1998.

As in 2016-17, the past year for Japan's nuclear industry can be characterized as making progress with restarting several reactors, but also some setbacks and significant uncertainties over future operation. A consistent majority of Japanese citizens, when polled, continue to oppose the continued reliance on nuclear power, support its early phase-out, and remain opposed to the restart of reactors. In the most recent polling, 48 percent of respondents said they are opposed to nuclear restart, while 32 percent said they supported restart.[143]

With retail market liberalization, there has been a noticeable loss of market share by nuclear utilities. While the government remains committed to nuclear power operation there are emerging signals of growing doubts over the scale of future nuclear generation.

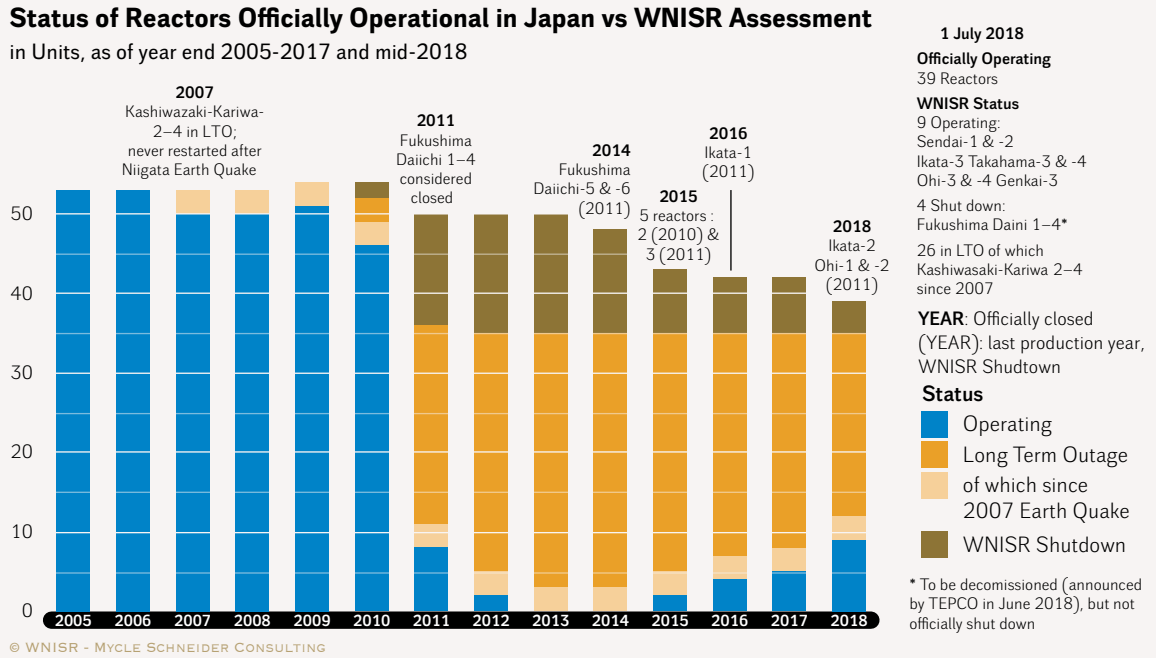
140 - WNISR, "Second Reactor Restarts in Japan", 22 October 2015, see https://www.worldnuclearreport.org/Second-Reactor-Restarts-in-Japan.html, accessed 28 April 2018.

141 - WNISR, "Takahama-4 Restart in Japan After Court Injunction Was Overturned", 22 May 2017, see https://www.worldnuclearreport.org/Takahama-4-Restart-in-Japan-After-Court-Injunction-Was-Overturned.html, accessed 28 April 2018.

142 - WNISR, "Ikata-3 Restarted—Only Three Reactors Operate in Japan", 17 August 2016, see https://www.worldnuclearreport.org/Ikata-3-Restarted-Only-Three-Reactors-Operate-in-Japan.html, accessed 28 April 2018.

143 - *The Mainichi*, "50% say no need for Diet to initiate constitutional reform in 2018: poll", 26 February 2018, see https://mainichi.jp/english/articles/20180226/p2a/00m/0na/019000c, accessed 30 April 2018.

Figure 23 | Status of Japanese Reactor Fleet



Sources: Various sources, compiled by WNISR, 2017

Reactor Restarts

As of 1 July 2018, four reactors resumed operation in the past year. On 16 March 2018, Japanese utility Kansai Electric Power Company (KEPCO) reconnected its reactor Ohi-3 to the grid, four and a half years after it was shut down on 2 September 2013.[144] On 11 May, the Ohi-4 reactor also was reconnected to the grid.[145] Restart of both units had been delayed as a consequence of the Kobe Steel falsification quality control scandal.[146] The Ohi nuclear plant has been the subject of multiple lawsuits since its shutdown. KEPCO submitted its applications to the Nuclear Regulation Authority (NRA) for safety examinations of Ohi-3 and -4 on 8 July 2013. On 24 May 2017, the NRA approved safety examinations for the two reactors.

A major issue at the **Ohi site** is the status of geologic faults within the site and the area around it. The seismic issue was a central element that led to the Fukui District Court issuing a landmark ruling on 22 May 2014 against the operation of the Ohi reactors.[147] The case was not an injunction as there was no immediate risk of restart. The Fukui Court ruled in favor of

144 - WNISR, "Japan: Ohi-3 Restarted After 4.5-Year Outage", 17 March 2018, see https://www.worldnuclearreport.org/Japan-Ohi-3-Restarted-After-4-5-Year-Outage.html, accessed 29 April 2018.

145 - Kansai Electric Power Co., "Start of Power Generation at Ohi Unit No. 4", 11 May 2018, see http://www.kepco.co.jp/english/corporate/pr/2018/__icsFiles/afieldfile/2018/05/11/2018_may11_2.pdf, accessed 14 July 2018.

146 - JAIF, "Ohi-4 NPP Restarted, Kansai EP to Lower Rates 4%", Japan Atomic Industrial Forum, 10 May 2018, see http://www.jaif.or.jp/en/ohi-4-npp-restarted-kansai-ep-to-lower-rates-4/, accessed 14 July 2018; also Shaun Burnie, "The Kobe Steel Group Supply Chain to the Nuclear Industry And Safety Implications", Greenpeace Germany, 24 October 2017, see https://www.greenpeace.org/japan/Global/japan/pdf/Kobesteel_20171024.pdf, accessed 14 July 2018.

147 - *Japan Times*, "Reflect on Fukui nuclear ruling", 23 May 2014, see https://www.japantimes.co.jp/opinion/2014/05/23/editorials/reflect-on-fukui-nuclear-ruling/#.WonkE9hKjOQ, accessed 14 July 2018.

200 plaintiffs, who contended that the plant was not sufficiently robust against active seismic faults.

Kunihiko Shimazaki, the former NRA deputy chair and a professor emeritus of seismology at the University of Tokyo, in July 2016, voiced strong concerns related to the Ohi reactors and his "sense of crisis" over the approach to earthquake risk analysis by the NRA.[148] The NRA, on 27 July 2016, announced that it would not be revising its seismic methodology, dismissing Shimazaki's assessment as "not up to a level that should be recommended by the NRA on the basis of scientific and technical sophistication." In summer 2016, Shimazaki submitted his analysis to the Kanazawa court, which is considering the KEPCO court appeal. On 4 July 2018, the High Court in Kanazawa ruled that the reactors could continue operation, overturning the 2014 ruling.[149]

Genkai-3 was reconnected to the grid 23 March 2018, more than seven years after it shut down in December 2010.[150] The 1180 MWe Pressurized Water Reactor (PWR), owned by the Kyushu Electric Power Company, is located in Genkai town, Saga Prefecture in southern Kyushu. Restart of the Genkai reactor had been delayed by two months due to the Kobe Steel scandal, where parts supplied to Kyushu Electric were required to be checked prior to restart.[151] On 19 June 2018, **Genkai-4** was reconnected to the grid, six and half years after it shut down in December 2011.[152] As with unit3, restart had been delayed due to the Kobe Steel scandal. They are Kyushu Electric's third and fourth reactors to resume operations, after Sendai units 1 & 2. Both Genkai units 3 & 4 passed NRA basic design approval in January 2017 and detailed design approval in August 2017.

Local approval from the host community (where the nuclear plant is sited) for restart was secured for Genkai in April 2017. However, four of the eight municipalities in three prefectures (Saga, Fukuoka and Nagasaki) within 30 km of the Genkai plant had expressed opposition to restart. On 20 March 2018, the Saga District Court rejected a temporary injunction against the restart of Genkai units 3 & 4.[153] A group of about 70 citizens in Saga and four other prefectures had filed a request for the provisional injunction in January 2017. The residents provided evidence that Kyushu Electric had underestimated the potential impact of earthquakes and volcano eruptions on the plant. NRA safety guidelines require a volcano assessment for all volcanoes within a 160-kilometer radius from nuclear plants. The active volcano Mount Aso is 130 km from Genkai. Kyushu Electric stated there is a low probability that the volcano will erupt while the plant is in operation, which the court accepted, and that the plant has appro-

148 - Osamu Tsukimor, Aaron Sheldrick, "Former Japan nuclear regulator lashes out over earthquake standards", *Reuters*, 15 July 2016, see https://af.reuters.com/article/worldNews/idAFKCN0ZV11C, accessed 29 April 2018.

149 - David Dalton, "Japanese High Court Says Operation Of Ohi-3 And-4 Can Continue", *NucNet*, 4 July 2018, see https://www.nucnet.org/all-the-news/2018/07/04/japanese-high-court-says-operation-of-ohi-3-and-4-can-continue, accessed 14 July 2018.

150 - Kyushu Electric Power Company, "Schedule of Startup and Restart of Generating Electricity of Genkai Nuclear Power Station Unit No. 3 ", Press Release, 22 March 2018, see http://www.kyuden.co.jp/var/rev0/0121/8751/lh47era4.pdf, accessed 29 April 2018.

151 - *Japan Times*, "Kobe Steel data scandal to delay restart of four nuclear reactors", 30 November 2017, see https://www.japantimes.co.jp/news/2017/11/30/national/kobe-steel-data-scandal-delay-restart-four-nuclear-reactors/#.WvBhQNMvyAw, accessed 28 April 2018.

152 - Kyushu Electric Power Co., "Restart of Generating Electricity of Genkai Nuclear Power Unit No.4", 19 June 2018, see http://www.kyuden.co.jp/en_information_180619.html, accessed 14 July 2018.

153 - Kenro Kuroda, Yuta Ichijo "Court denies injunction for restart of Genkai nuclear plant", *Asahi Shimbun*, 20 March 2018, see http://www.asahi.com/ajw/articles/AJ201803200038.html, accessed 29 April 2018.

priate safety measures to meet seismic impacts.[154] The plaintiffs are planning to appeal to the Fukuoka High Court.

In 2009, Genkai-3 became the first commercial reactor in Japan to operate with a partial plutonium-uranium mixed oxide (MOX) fuel core. Shut down in 2010 for maintenance, in March 2011, Genkai-3 was loaded with 16 assemblies of MOX fuel supplied by the French company AREVA (now ORANO), bringing the MOX fuel core to 32 assemblies. The reactor was not restarted following the Fukushima Daiichi accident and the unirradiated 16 MOX assemblies were unloaded in 2013. Citizens opposed to the operation of the Genkai reactor using MOX fuel had filed in evidence in 2010 of the risk of fuel cladding gap reducing the safety margins of the reactor.[155] In March 2015, the Saga district court ruled against the plaintiffs citing that they had failed to demonstrate a safety risk.[156]

Permanent Closures

Kansai Electric Power Company (KEPCO) confirmed in December 2017 that it would decommission the **Ohi units** 1 & 2, 40 and 39 years respectively after they were connected to the grid. The 1120 MWe reactors, the largest to be declared for shutdown so far in Japan, were in Long-Term Outage (LTO) since they last operated in July and December 2011. Speculation over the future of the reactors emerged in October, when it was reported that a decision had been made to permanently shut the reactors due to the costs of retrofits.[157] KEPCO initially denied that a decision had been taken, stating that it was assessing costs for safety modifications needed to meet regulatory requirements and that it was preparing to apply for regulatory review to the NRA.[158]

KEPCO's total projected retrofit costs for the currently operating the Takahama-3 & -4 reactors and Ohi-3 & -4, and the older Takahama-1 & -2 and Mihama-3 reactors, was reported to be costing the utility 830 billion yen (US$7.6 billion), while the cost would rise to over 1 trillion yen (US$9.1 billion),[159] if the Ohi-1 & -2 were included.

The NRA announced 18 October 2017 that it would require Ohi-1 & -2 to install filtered containment vents that allow for depressurization of the containment vessel in case of an accident, because they are the only Pressurized Water Reactors (PWRs) in Japan that use an ice condenser containment design. In such designs, ice is maintained inside the vessels to provide additional cooling capacity in case of the release of high-temperature steam from the reactor vessel in an accident. This allows use of a smaller containment than in other PWRs.

154 - Kyushu Electric Power Company, "Rejection of the Temporary Injunction against Restart of Genkai Nuclear Power Station Units No.3 and 4 (Kyushu Electric Power Prevails in Court)", Press Release, 20 March 2018, see http://www.kyuden.co.jp/var/rev0/0121/8206/lty47qg8.pdf, accessed 29 April 2018.

155 - CNIC, "Lawsuit to Stop the Use of MOX Fuel at Genkai-3", News Watch 138, Citizens Nuclear Information Center, October 2010, see http://www.cnic.jp/english/newsletter/nit138/nit138articles/nw138.html#genkai, accessed 29 April 2018.

156 - *Osamu Tsukimori, Tom Hogue "Japan court denies injunction against MOX nuclear fuel use", Reuters*, 20 March 2015, see https://www.reuters.com/article/us-japan-nuclear-kyushu-elec-pwr/japan-court-denies-injunction-against-mox-nuclear-fuel-use-idUSKBN0MG11T20150320?irpc=932, accessed 15 July 2018.

157 - *Nikkei Asian Review*, "Japan's Kansai Electric to shut down 2 major nuclear reactors", 17 October 2017, see https://asia.nikkei.com/Business/Japan-s-Kansai-Electric-to-shut-down-2-major-nuclear-reactors, accessed 29 April 2018.

158 - *NW*, "Kansai Electric assessing safety costs for potential Ohi unit restarts", 2 November 2017.

159 - Ibidem.

In November 2017, energy analysts questioned, whether such a large investment in Ohi-1 and -2, could be justified, particularly as KEPCO faces reduced market share and competition as a result of market liberalization. "It's hard to say spending billions of dollars on safety measures to restart Ohi-1 and -2 would support the bottom line at Kansai Electric," Norimasa Shinya, an analyst at Mizuho Securities Co. told *Nucleonics Week* (*NW*),[160] noting that, "since the 2011 Fukushima accident, consumers have tended to save electric power." KEPCO's electricity supplied to customers shrank by 29 percent in the fiscal year through March 2017 compared to fiscal year that ended in March 2011. Tomoko Murakami, general manager of the nuclear energy group at the Institute of Energy Economics of Japan stated: "Their shareholders would not be happy about it [spending billions]."[161]

Two months later on 22 December 2017, KEPCO confirmed that both Ohi reactors would be decommissioned.[162] Citing the challenges and consequences of strengthening the reactor containment building, which due to the relatively small physical size of the ice condenser reactors, would negatively affect routine inspection, maintenance and repair, the utility had taken to decision to decommission. The Ohi units have a combined capacity of 2,350 MW and are the largest reactors in Japan to be slated so far for permanent shutdown.

On 27 March 2018, Shikoku Electric Power Company announced that its Board of Directors had taken the decision for the permanent shutdown of the 36-year-old **Ikata-2** reactor.[163] The 538 MW PWR, located in Ehime Prefecture on the island of Shikoku, was connected to the grid on 19 August 1981 and had not operated since January 2012. Shikoku Electric considered that it would be unprofitable to resume operations at the plant with required safety retrofits of an estimated 200 billion yen (US$1.9 billion).[164] The decision comes almost exactly two years after the utility announced its decision to decommission its Ikata-1 reactor.[165] As with the earlier decision, it reverses a commitment of Shikoku Electric to restart the reactor. The closure leaves the utility with only one operational reactor, the 846 MWe Ikata-3, which restarted 16 August 2016,[166] but which as of 1 July 2018 remains shutdown due to the ruling of the Hiroshima High Court in December 2017.

The decision to close Ikata-2, brings to nine the number of commercial reactors announced for decommissioning since 2015, in addition to the six reactors at Fukushima Daiichi, and the Monju prototype Fast Breeder Reactor (see Table 4).[167] On 6 December 2017, the Japan Atomic Energy Agency (JAEA) applied to the Nuclear Regulatory Agency (NRA) for the decommis-

160 - Ibidem.

161 - Ibidem.

162 - KEPCO, "Decision on the decommissioning of units 1 and 2 of Ohi nuclear power station", 22 December 2017, see http://www.kepco.co.jp/english/corporate/ir/brief/pdf/2017_dec22_1.pdf, accessed 29 April 2018.

163 - Shikoku Electric Power Company, "About the shutdown of Ikata-2", see http://www.yonden.co.jp/press/re1803/data/pr008.pdf, accessed 29 April 2018.

164 - *Asahi Shimbun*, "Shikoku Electric to scrap aging, costly Ikata No. 2 reactor", 27 March 2018, see http://www.asahi.com/ajw/articles/AJ201803270053.html, accessed 29 April 2018.

165 - WNISR, "Permanent Closure of Japanese Reactor Ikata-1", 26 March 2016, see https://www.worldnuclearreport.org/Permanent-Closure-of-Japanese-Reactor-Ikata-1.html, accessed 29 April 2018.

166 - WNISR, "Ikata-3 Restarted—Only Three Reactors Operate in Japan", 17 August 2016, see https://www.worldnuclearreport.org/Ikata-3-Restarted-Only-Three-Reactors-Operate-in-Japan.html, accessed 29 April 2018.

167 - Mycle Schneider et al., "The World Nuclear Industry Status Report 2017", September 2017, see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2017-HTML.html#link182, accessed 29 April 2017.

sioning of the Monju FBR, thereby officially designating it a permanently closed reactor.[168] As noted in WNISR2017, while the decision has taken years to be made, and to some extent is merely the Japanese government catching up with the reality of a failed project, it also reflects the ongoing crisis in the nation's nuclear energy policy.

Table 4 | Official Reactor Closures Post-3/11 in Japan

Operator	Reactor	Capacity MW	Startup Year	Shutdown Announcement[a] dd/mm/yy	Official Shutdown 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)	760	1979	19/12/13	31/01/14	2011	32
KEPCO	Mihama-1 (PWR)	340	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)	1120	1977	22/12/17	01/03/18	2011	34
	Ohi-2 (PWR)	1120	1978	22/12/17	01/03/18	2011	33
KYUSHU	Genkai-1 (PWR)	529	1975	18/03/15	27/04/15	2011	37
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)	341	1969	17/03/15	27/04/15	2011	41
CHUGOKU	Shimane-1 (PWR)	439	1974	18/03/15	30/04/15	2010	37

Sources: JAIF, Japan Nuclear Safety Institute, compiled by WNISR, 2018

Notes

a - Unless otherwise specified, all dates from Japan Nuclear Safety Institute, "Licensing status for the Japanese nuclear facilities", 16 June 2018, see http://www.genanshin.jp/english/facility/map/, accessed 18 June 2018.

b - All 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 23 July 2018.

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 LTS (IAEA-Category Long Term Shutdown) since December 1995.

In September 2016, the Fukushima Prefectural government announced that it is planning to work with 11 municipalities to reach a collective agreement with Tokyo Electric Power Company (TEPCO) on assessing the safety of the four Fukushima Daini reactors, the objective

168 - Noriyuki Ishii, "JAEA Officially Classifies Monju Fast Reactor as "Closed Down", JAIF, 12 December 2017, see http://www.jaif.or.jp/en/jaea-officially-classifies-monju-fast-reactor-as-closed-down/, accessed 30 April 2018.

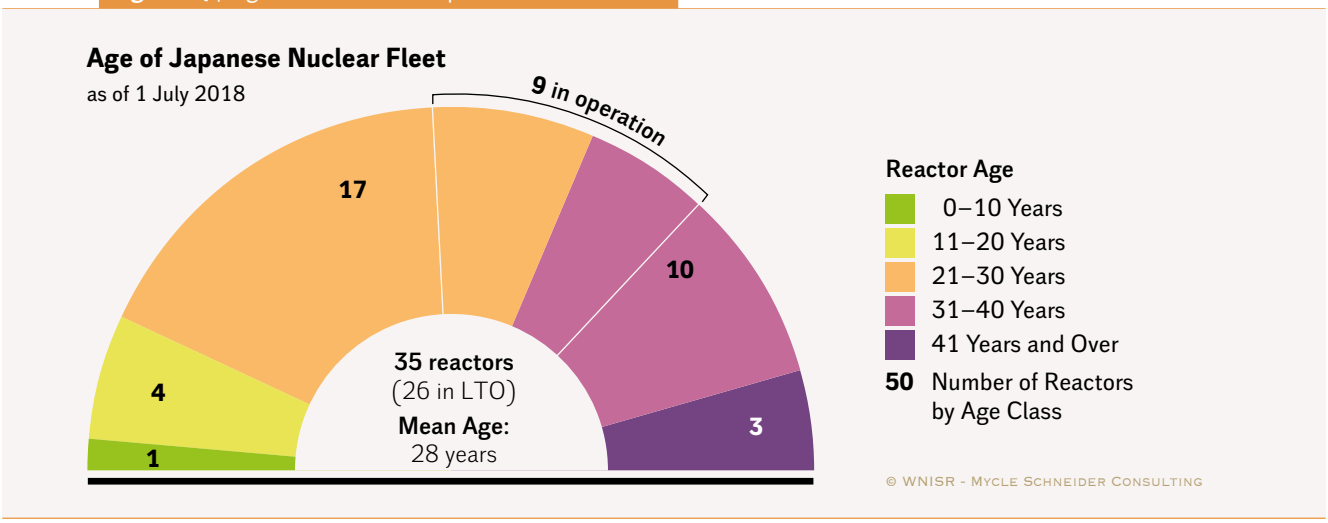
being the permanent shutdown of the plant. WNISR has taken them off the list of operating reactors in the first edition following 3/11.

The nine reactors to be decommissioned had a total installed generating capacity of 5.4 GW, equal to 13 percent of Japan's operational nuclear capacity as of March 2011.[169] Together with the ten Fukushima units, the total rises to 19 reactors and 14.2 GW or one third of installed nuclear capacity prior to 3/11 that has been permanently removed from operations.

Factors determining a decision to decommission are age, capacity, the reactor fleet profile, and the investment cost to bring the reactor into compliance with revised post-Fukushima guidelines. In October 2017, the Federation of Electric Power Companies (FEPC) reported a year-on-year increase of 500 billion yen (US$4.4 billion) to a total of 4 trillion yen (US$35 billion) spent or assigned by nuclear utilities to cover the costs of safety retrofits to their reactor fleet.[170]

Future likely candidates for permanent shutdown are Kyushu Electric's 559 MW, 38year old Genkai-2 and the 524 MW Onagawa-1, owned by Tohoku Electric Power Company. Kyushu Electric stated that it "could enter serious discussions about the future of Genkai-2 after restarting Genkai-3 and -4" in 2018.[171] While Tohoku Electric stated: "We intend to restart it, but we haven't reached a conclusion, whether we can do so, because we have to evaluate safety costs and a return from that investment." The utility currently has not reactors operating, with unit 2 delayed a further two years from 2019 to 2021.[172] There remains considerable doubt over the future of multiple Chubu Electric's Hamaoka reactors.[173]

Figure 24 | Age Distribution of Japanese Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2018

169 - Based on a total installed capacity of 47.37GW and not including the 246MW Monju FBR.

170 - *NW*, "Safety costs might lead to more Japan nuclear units being retired: analysts", 16 November 2017.

171 - Ibidem.

172 - *Platts*, "Nuclear News Flashes", 26 April 2018.

173 - *NW*, "Japan's Hamaoka-4 facing local government opposition to restart", 6 July 2017.

A number of the seven Kashiwazaki Kariwa reactors also remain likely candidates for decommissioning, though the resignation of the governor of Niigata in April 2018 makes the timetable for any announcement on this even less clear.

The Japanese nuclear fleet's mean age now stands at 28 years with 13 units over 31 years (see Figure 24).

Restart Prospects

With nine reactors having officially restarted operation, nuclear generation during the first months of 2018 was nevertheless limited due to planned maintenance outage of the Ikata-3 and Sendai1 & 2 reactors, as well as delays to resumption of Genkai and Ohi reactors due to the Kobe Steel scandal emerging in 2017.[174] Barring further technical problems and court rulings, WNISR expects there to be nine reactors in operation by the fourth quarter of 2018, but with major uncertainties as to prospects thereafter.

In April 2018, the Nuclear Regulation Authority (NRA) reported on the status of reactor safety review. A total of 14 reactor units have had their safety upgrade plans approved by NRA commissioners, the first of a three-stage process prior to actual operation, the other two being engineering works program as well as pre-operational inspections. A total of 26 reactors have applied for NRA safety assessment, with Hokuriku Electric Power Company reporting, in April 2017, it plans to apply for a safety review for Shika-1 to NRA, but with no specified date. Of the 14 reactors that have passed the initial safety review stage, three reactors, Takahama-1 and -2 and Mihama-3 are undergoing extensive retrofits and are not planned to restart before 2019 and 2020 respectively. As of 1 July 2018, only Pressurized Water Reactors (PWRs) have resumed operation in Japan. However, in a significant step, the NRA, on 27 December 2017, approved the initial safety assessment for Tokyo Electric Power Holding Company's (TEPCO) Kashiwazaki Kariwa units 6 & 7,[175] the first Boiling Water Reactors (BWR) to reach this stage of NRA review.[176] The future operation of these two 1315MW reactors are central to both the future of TEPCO as a nuclear generating company and to some extent the wider operation of BWRs in Japan. The future operation of TEPCO's nuclear plant at Kashiwazaki Kariwa, in Niigata prefecture on the Sea of Japan coast, remains highly uncertain, but prospects improved for an eventual restart of units 6 & 7 with the resignation of the Niigata governor, a nuclear critic, in April 2017.[177] The Niigata governor election of 10th June 2018 led to the appointment of Liberal Democratic Party (LDP) backed candidate Hidey Hanazumi. However, this does not mean any early restart for TEPCOs Kashiwazaki Kariwa reactors. The newly elected governor

174 - *Japan Times*, "Kobe Steel data scandal to delay restart of four nuclear reactors", 30 November 2017, see https://www.japantimes.co.jp/news/2017/11/30/national/kobe-steel-data-scandal-delay-restart-four-nuclear-reactors/#.WvBhQNMvyAw, accessed 28 April 2018; and Shaun Burnie, "The Kobe Steel Group Supply Chain to the Nuclear Industry And Safety Implications", Greenpeace Japan, 24 October 2017, see https://www.greenpeace.org/japan/Global/japan/pdf/Kobesteel_20171024.pdf, accessed 28 April 2018.

175 - 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, see http://www.tepco.co.jp/en/press/corp-com/release/2017/1470967_10469.html, accessed 30 April 2018.

176 - 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 30 April 2018.

177 - *Reuters*, "Governor of Japan's Niigata resigns to avoid 'turmoil' over magazine article", 18 April 2018, see https://www.reuters.com/article/us-japan-nuclear-governor/governor-of-japans-niigata-resigns-to-avoid-turmoil-over-magazine-article-idUSKBN1HP1EP, accessed 30 April 2018.

conscious that 65 percent of the Niigata population remain opposed to restart of any reactors at the plant, stated, "As long as the people of Niigata remain unconvinced, (the reactors) won't be restarted,".[178] The previous Governor of Niigata appointed a panel of experts to review the causes and impacts of the Fukushima Daiichi accident and to review emergency planning in Niigata in the event of a severe accident at the Kashiwazaki Kariwa plant.[179] The conclusion of the work of the committees was linked to the then Governor's determination of approval or not for the restart of units 6 & 7. They were expected not conclude their investigations until mid-2020 at the earliest. The committees work is ongoing, and the new Governor has stated 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[180]

Highlighting the uncertainty of reactor operation for both utilities and Government was a first-of-its-kind ruling made by the High Court in Hiroshima on 13 December 2017 against the restart of Ikata-3.[181] Scheduled to return to operation in January 2018, the Hiroshima court ruled in favor of citizens who had filed against operation of the reactor on grounds of seismic and volcano risks. The plant is at risk from the massive Nankai Trough and the Median Tectonic Line fault belt—Japan's largest-class and longest fault zone, which runs near the Ikata plant site. The Hiroshima court decision overturned an earlier lower court decision made in March 2017 that ruled against the citizens. As a consequence, Ikata-3 is prevented from resuming operations at least until September 2018. Shikoku Electric, the plants owner, expressed its disappointment at the ruling and filed an appeal.[182] The Hiroshima ruling is significant in terms of it being the first time a higher court has overturned a lower court's ruling on nuclear reactor restarts, and also due to the prominence it gave to the issue of volcanic eruption risks to nuclear plant safety. Administrative lawsuits and other injunction requests against Ikata-3 have also been filed with other district courts in nearby Matsuyama, Yamaguchi and Oita. While it is likely that the Ikata-3 reactor will resume operations later in 2018, the court decision underscores the impact of on-going and future legal challenges faced by utilities.

In 2017, WNISR suggested that as many as seven reactors might be operating in Japan by December 2017 and nine by March 2018. The Kobe Steel scandal set back plans for four reactor restart and the Ikata-3 court ruling meant that in the end only five reactors were in operational status as of end of 2017. The expectation is that there will be no further restarts soon and not more than nine reactors will be operating by the end of fiscal year 2018, in March 2019.

Given the past seven years of nuclear power plant operation, this has still to be considered a significant step forward for the utilities owning these reactors. At the same time, it has to be seen in the context of national electricity generation system: with nine reactors operating in

178 - 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 11 August 2018.

179 - Kentaro Hamada, 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 15 July 2018.

180 - *Asahi Shimbun*, "LDP-backed candidate wins governor's race in Niigata", 11 June 2018, see http://www.asahi.com/ajw/articles/AJ201806110049.html, accessed 15 July 2018.

181 - *WNN*, "High court orders suspension of Ikata 3 operation", 13 December 2017, see http://www.world-nuclear-news.org/RS-High-court-orders-suspension-of-Ikata-3-operation-1312174.html, accessed 28 April 2018.

182 - Shikoku Electric Power Company, "Unit 3 Of Ikata Power Plant In The Appeal Court In Hiroshima High Court - On The Appeal Against The Decision On Temporary Disposition Of Injunction", 21 December 2017, (in Japanese), see http://www.yonden.co.jp/press/re1712/data/pr007.pdf, accessed 28 April 2018.

2018, the nuclear share would be in the range of 6.5 percent, compared with 29 percent in 2010. Harder to assess are the prospects for any restart of BWRs during the coming few years, none having resumed operations to date. The pace of restart beyond 2018 remains highly uncertain, due to a number of factors:

- The Abe government remains committed to the earliest possible restart of reactors. However, outside the NRA process, there are important external factors that will continue to determine how many nuclear reactors will eventually resume operations. These include: Continuation of citizen-led lawsuits, including injunctions against restart.
- Economic factors, including a cost-benefit analysis by the utilities on the implications of restart or shutdown.
- Local political and public opposition.
- Impact of electricity deregulation and intensified market competition.

At the same time, however, Japanese utilities are insisting, and the government has granted and reinforced, the right to refuse renewable power, supposedly due to concerns about grid stability—hardly plausible in view of their far smaller renewable fractions than in several European countries—but apparently to suppress competition. Indicative of the uncertain future for the main utilities, TEPCO, KEPCO and Chubu Electric reported continued customer losses during 2017, in total they have lost 5.7 million retail power customers, equal to 6.7 percent of Japan's total,[183] who have switched to new suppliers, since the electricity market was liberalized in April 2016.[184]

The utilities also continue strenuous efforts to ensure that the imminent liberalization of the monopoly-based, vertically integrated Japanese power system should not actually expose utilities' legacy-plants to real com- petition. The ability of existing Japanese nuclear plants, if restarted, to operate competitively against modern renewables (as many in the U.S. and Europe can no longer do) is unclear because nuclear operating costs are not transparent. However, the government's almost complete suppression of Japanese wind power in recent years suggests that they are concerned on this score.[185]

Of the 26 reactors in LTO—plus one officially under construction (Ohma)—16 of which have applications outstanding before the NRA at different stages of the procedure. Not all will restart, with many questions and disagreements over seismic issues, and many plants far back in the review and screening queue. At the present rate of review, restart of three to four reactors each year from 2018 onwards remains an increasingly remote possibility, but also a challenge, with the major uncertainty that even restarted reactors will be shut down through the courts. In this sense, the future of nuclear power in Japan remains highly uncertain.

Figure 25 shows the collapse of nuclear electricity generation in Japan, declining by a factor of 10, from 280 TWh in 2010 to 29 TWh in 2017. While the most dramatic decline has been

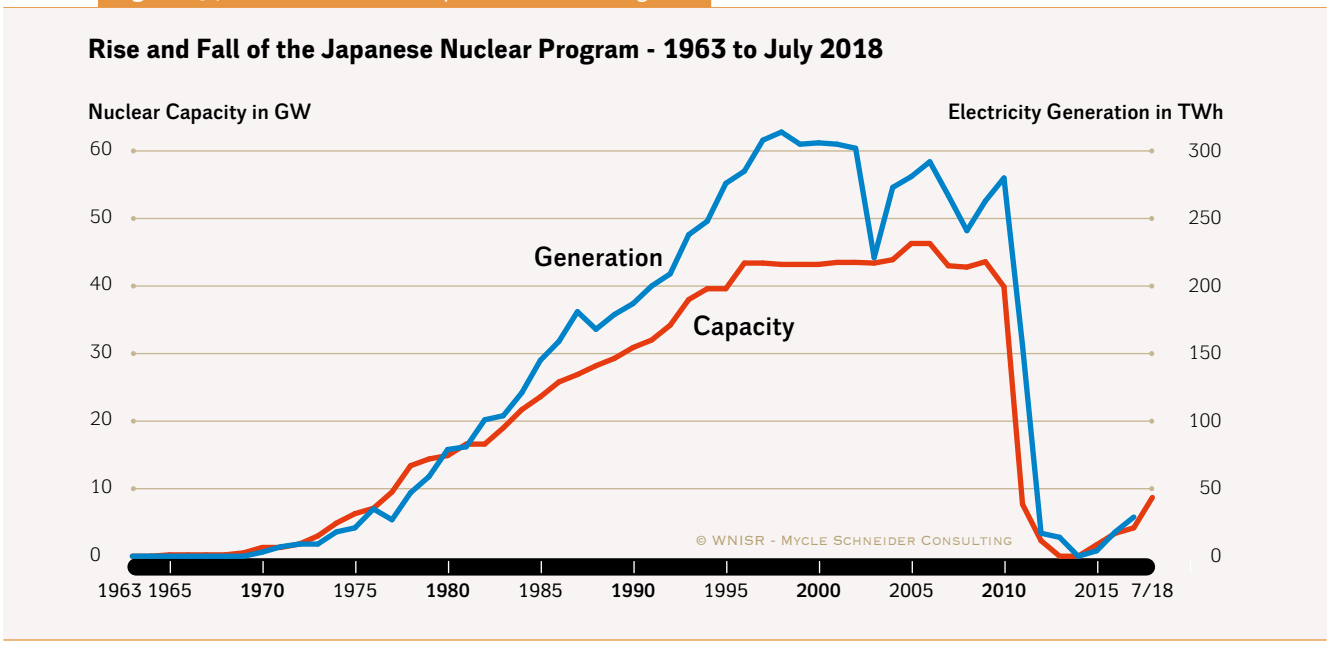
183 - ESG, "ESG's Retail Energy Enterprise Solution (REES) Is Ready For Japan", Energy Service Group, April 2017, see https://www.energyservicesgroup.net/wp-content/uploads/2017/04/REES-Japan.pdf, accessed 15 July 2018.

184 - Osamu Tsukimori, "Japan's top power utilities see power sales decline", *Reuters*, 27 April 2018, see https://uk.reuters.com/article/us-japan-electricity/japans-top-power-utilities-see-power-sales-decline-idUKKBN1HY1I1, accessed 30 April 2018.

185 - In comparison to solar PV, there has been extremely slow expansion of wind power in recent years, contributing 0.5 percent to national electricity generation in 2015. Total installed capacity as of January 2016 was 3 GW (offshore and onshore), with a further 7 GW stuck in the bottle neck of an environmental assessment. There are prospects of change however, in particular with offshore wind. Currently only 52.6 MW of installed capacity is offshore.

since the Fukushima Daiichi accident started in 2011, in fact it is 20 years since Japan's nuclear output peaked at 313 TWh in 1998. The noticeably sharp decline during 2002-2003, amounting to a reduction of almost 30 percent, was due to the temporary closure of all 17 of TEPCO's reactors. The shutdown was the consequence of an admission from TEPCO that its staff had deliberately falsified data for inclusion in regulatory safety inspections reports. During 2003, TEPCO managed to resume operations of five of its reactors. The further noticeable decline in electrical output in 2007 was the result of the extended shutdown of the seven Kashiwazaki Kariwa reactors, following the Niigata Chuetsu-oki earthquake. TEPCO was struggling to restart the Kashiwazaki Kariwa units when the Fukushima earthquake occurred.

Figure 25 | Rise and Fall of the Japanese Nuclear Program



Sources: WNISR, with IAEA-PRIS, 2018

Energy Policy

The government of Prime Minister Abe stated in 2015 that a nuclear share in power generation of 20-22 percent, renewable energy of 22-24 percent, and fossil fuels 56 percent would be achieved by 2030.[186] Challenges to the proposed nuclear share were evident inside the drafting subcommittee, with dissenting expert opinions that the nuclear share did not reflect a 2014-commitment to reduce nuclear power to the extent possible. To attain that nuclear share, all 26 reactors that have applied for NRA review would have to be operating, plus five to ten of those yet to be reviewed, a prospect that in reality appears unattainable. A 15-percent target would require either the operation of all of these 26 reactors, and therefore include the operation of reactors beyond their 40-year lifetime; or a combination of 40-year-plus reactors together with additional reactors that have yet to apply for review.

186 - Kenji Kaneko, "Japan Announces Energy Mix Plan for 2030", Nikkei BP CleanTech Institute, published in *Solar Power Plant Business*, 1 May 2015, see http://techon.nikkeibp.co.jp/english/NEWS_EN/20150501/416800/?ST=msbe, accessed 30 April 2018.

The Japanese government launched a revision of its Strategic Energy Plan during 2017 with the aim of a revised plan approved by the Cabinet during 2018. The Ministry for Economy, Trade and Industry (METI) restated that the new plan will retain the current version's commitment to reducing dependence on nuclear energy "to the extent possible" and advocating accelerated adoption of wind, solar and other renewable energy sources. Energy policy in Japan is framed as 3E+S" (Energy Security, Economic Efficiency, Environment + Safety), which until the present METI and the utilities means that nuclear power must remain a central element in future electricity supply.[187] Indications are that this is slowly shifting.

In September 2017, Japan's Atomic Energy Commission (JAEC) issued its first White Paper on nuclear energy since the 2011 Fukushima Daiichi accident. It noted that it shall continue to "establish a safety culture that overcomes weakness of traditional Japanese organizations and national cultures; and a shift in safety assurance of a 'culture of prevention' by promotion of risk management." While also pursuing "nuclear energy use addressing global warming issues and people's livelihood and the economy" and that "The National Government needs to clarify the role that nuclear power generation can play over a long term and examine necessary measures."[188]

In March 2018, METI released a draft strategy by a roundtable of experts studying the nation's energy policy through 2050, calling renewables an "energy source whose possibility of becoming a major (source) is greatly increasing."[189] The panel is tasked with developing an energy plan to bring Japan into compliance with the Paris Agreement goals for 80 percent greenhouse gas emissions reduction by 2050 over 2013 levels. Currently, Japanese policy is to reduce emissions by 8-12 percent below 1990 levels in 2030 (excluding land use, land-use change, and forestry or LULUCF), which is generally considered highly insufficient, meaning that if all countries were to adopt this level of ambition, global warming would likely exceed 3-4 degree centigrade in the 21st century[190]

The final strategy document was released in early April 2018, confirming that "Japan will keep the policy of lowering its dependency on nuclear power generation as much as possible while seeking to expand economically independent and carbon-free renewable energy."[191] The report notes that pursuing nuclear power means dealing with decommissioning reactors and disposing of waste, not to mention regaining the public's trust following the 2011 meltdowns at the Fukushima Daiichi plant. The report did not establish specific numerical percentages of the country's future energy mix in 2050.

187 - METI, "Key Points of Recommendations by the Round Table for Studying Energy Situations—Initiatives for Energy Transitions", Ministry for Economy, Trade and Industry, 13 April 2018, see http://www.enecho.meti.go.jp/en/committee/studygroup/ene_situation/pdf/keypoints.pdf, accessed 30 April 2018.

188 - JAEC, "Summary of "White Paper on Nuclear Energy 2016", September 2017, (Provisional Translation), 28 November 2017, see http://www.aec.go.jp/jicst/NC/about/hakusho/hakusho2016/gaiyo_1_e.pdf, accessed 30 April 2018.

189 - *Japan Times*, "In long-term plan, Japan set to confirm renewables as 'major' energy source", 30 March 2018, see https://www.japantimes.co.jp/news/2018/03/30/business/long-term-plan-japan-set-confirm-renewables-major-energy-source/#.WvHOi9MvzOQ, accessed 30 April 2018.

190 - Climate Action Tracker, "Japan", April 2018, see https://climateactiontracker.org/countries/japan/, accessed 15 July 2018.

191 - *The Japan Times*, "Japan pushes renewables, keeps nuclear in energy plan through 2050", 10 April 2018, see https://www.japantimes.co.jp/news/2018/04/10/national/japan-pushes-renewables-keeps-nuclear-energy-plan-2050/#.WvHNp9MvzOQ, accessed 30 April 2018.

While the option of constructing new nuclear reactors had emerged in late 2017,[192] the METI report made no mention of this option, though it does call for the "pursuit of reactors that are safer and more economical."[193] The METI 2050 strategy report will feed into an energy plan for 2030 that was scheduled for release in July 2018.

In a further indication of the political pressure building against current nuclear and overall energy policy in Japan, two developments are worth highlighting. On 9 March 2018, the newly formed Constitutional Democratic Party presented its "Nuclear Zero Bill" to the lower house of the Diet (parliament), that would require the government to pursue a policy goal of shutting down all nuclear reactors in Japan within five years after the legislation takes effect, with the goal of expanding the use of renewable energy sources.[194] The bill will not pass due to the majority of the ruling Liberal Democratic Party, but signals for the first time Japan's main opposition party as being committed to a rapid phase out of nuclear power.

> *"there is a recognition that business as usual in Japan is not an option"*

Secondly, Foreign Minister Taro Kono established in 2017 a panel of experts to advise his office on Japan's energy policy in the context of its Paris climate commitments. The report from the panel, following a series of meetings in early 2018, signals that at least at this arm of government there is a recognition that business as usual in Japan is not an option. The 19 February 2018 report states: [195]

> The argument that nuclear and coal-fired power, as baseload power sources, are necessary to ensure stable power supply is already outdated. The countries with a matured electricity market have shifted to a new system with a maximum use of renewable energy available at low marginal cost, and then together with flexible electric power sources including natural gas-fired power for the rest of electricity demand. Electricity trading and broader management of transmission system with weather forecast as well as demand response provide flexibility and assurance to the grid management. The roles played by less flexible nuclear and coal-fired power in generating electricity have gradually been reduced.

And that,

> Adhering to an energy technology that is high investment risk and lacks flexibility will prevent renewable energy from expanding, detrimental to the nation's energy transition.

While only an advisory panel, and while the Ministry of Foreign Affairs (MOFA) does not determine energy policy in Japan, it is unprecedented that a report commissioned by a Liberal Democratic Party minister would describe nuclear power in these terms.

192 - *NW*, "Japanese government may seek new nuclear plants by 2050, analysts say", 5 October 2017, which reports Satoru Katsuno, chairman of Japan's Federation of Electric Power Companies (FEPC) and president of Chubu Electric Power Company stated 15 September 2017, that he is looking for the government to mention the option of building new reactors in its 2050 energy plan.

193 - *Nikkei Asian Review*, "Renewables to form core of Japan's new long-term energy strategy" 30 March 2018, see https://asia.nikkei.com/Politics/Renewables-to-form-core-of-Japan-s-new-long-term-energy-strategy, accessed 30 April 2018.

194 - *Asahi Shimbun*, "EDITORIAL: Opposition CDP's zero nuclear bill merits earnest debate in Diet", 24 February 2018, see http://www.asahi.com/ajw/articles/AJ201802240020.html, accessed 30 April 2018; and CNIC, "Nuclear Zero Bill Submitted to the Diet", Citizens Nuclear Information Center, 2 April 2018, see http://www.cnic.jp/english/?p=4102, accessed 30 April 2018.

195 - Advisory Panel to the Foreign Minister on Climate Change, "Recommendations on Energy: Promote new diplomacy on energy through leading global efforts against climate change", MOFA, 19 February 2018, see http://www.mofa.go.jp/files/000335212.pdf, accessed 30 April 2018.

Meanwhile the uncertainties remaining with the prospects for reactor restart mean that, no matter what target percentage is set in the next strategic energy plan, the Japanese Government and utilities simply cannot reliably plan on how many of Japan's remaining 26 reactors in LTO will be restarted, nor when.

The 2014 Strategic Energy Plan maintained the long-standing government policy of promoting spent nuclear fuel reprocessing and plutonium mixed oxide fuel (MOX) use in commercial reactors. In a further signal of tensions and challenges within Japan's nuclear industry, the Federation of Electric Power Companies (FEPC), which represents the nation's ten nuclear power utilities, announced on 20 November 2016 the indefinite postponement of a target date for loading plutonium MOX fuel into 16-18 reactors.[196] The plans to use MOX fuel have for the past two decades been the justification used for Japan's accumulation of separated plutonium. With the restart during the past 12 months of Genkai-3, four of the seven reactors in operational status in Japan are partially loaded with MOX fuel. On 14 March 2018, the Federation of Electric Power Companies (FEPCO) restated its intention to use the MOX fuel at sixteen to eighteen nuclear power plants (NPPs) nationwide, but with no target date, and no indication how it plans to reach that level of plutonium utilization.[197] The Japan Atomic Energy Commission (JAEC) is currently reviewing Japan's official basic policy on the utilization of plutonium. Not unexpectedly, and to the relief of the Abe government, the Trump administration signaled in January 2018, that the 30-year-old U.S.-Japan nuclear cooperation agreement will be automatically extended indefinitely July 2018.[198] The agreement, signed in 1988, provides the basis for Japan's nuclear program, and in particular its plutonium program. Senior officials in the White House, as well as at the State Department during the previous Obama administration, as well as members of Congress, had raised serious concerns over Japan's continued accumulation of plutonium during recent years.[199] While the diplomatic basis for Japan's plutonium program has been secured, neither the government or utilities are any closer to finding a credible solution to its plutonium stockpile, tied as it is to overall nuclear reactor operation as well as the uncertain future of the Rokkasho-mura reprocessing plant.

New-Build Projects

As in 2016-17, the situation of new-build projects during the past year is another illustration of the level of uncertainty surrounding the future of nuclear power in Japan. After the 3/11 events, Japan halted work at two ABWR units, Shimane-3 and Ohma, which had been under construction since 2007 and 2010 respectively. In September 2012, the Ministry for Economy, Trade and Industry (METI) approved the restart of construction at both sites, but there was little sign of any resumption of work. Officially, construction "partially resumed" at Ohma in October 2012 and Shimane-3 has remained "under construction and is almost complete", according to the

196 - *Nucleonics Week*, "Japan postpones plans to use MOX fuel", 26 November 2015.

197 - JAIF, "FEPC Adheres to Policy of MOX Fuel Use at 16 to 18 NPPs" Japan Atomic Forum, 16 March 2018, see http://www.jaif.or.jp/en/fepc-adheres-to-policy-of-mox-fuel-use-at-16-to-18-npps/, accessed 30 April 2018.

198 - Tomoyuki Kawai, "Japan and US to extend civilian nuclear pact", *Nikkei Asian Review*, 18 January 2018, see https://asia.nikkei.com/Politics/International-Relations/Japan-and-US-to-extend-civilian-nuclear-pact, accessed 30 April 2018.

199 - Masakatsu Ota, "End to breeder reactor, plutonium pile-up are twin problems for Japan's reprocessing policy", *Japan Times*, 21 September 2016, see https://www.japantimes.co.jp/news/2016/09/21/national/end-breeder-reactor-plutonium-pile-twin-problems-japans-reprocessing-policy/#.WvL6udMvzOQ, accessed 30 April 2018.

Japan Atomic Industrial Forum (JAIF)[200] and International Atomic Energy Agency (IAEA) statistics. In the case of Shimane-3, it was said to be 94 percent complete by March 2011.[201]

No startup date has been declared for the Shimane-3 reactor, while the owner, Chugoku Electric Power Company, is drawing up an application to the Nuclear Regulatory Authority (NRA) for permission for a change in reactor installation license. On 22 May 2018, Chugoku announced that it was seeking local community approval to apply to the NRA for review of the Shimane-3 reactor which is nearing completion of construction.[202] The application is directly tied to the status of Shimane-2, which is under NRA review. On 16 February 2018, the NRA signed off on the utility's basic earthquake ground motion as the likely maximum quake that could occur at the site.[203] "Now that we have approval for the basic earthquake ground motion for the No. 2 reactor, we will work toward also applying for a safety screening for the No. 3 reactor," said a utility official.[204] Before Chugoku Electric can apply to the NRA for a safety screening, it must gain the consent of the host Shimane prefectural authorities and the local Matsue municipal government.

In the case of Ohma, which was 40 percent complete by March 2011, the plant owner, the Electric Power Development Company (EPDC), also known as J-Power, declared that reinforced safety measures are to be implemented that take into account the lessons learned from the Fukushima accident, which include tsunami countermeasures, ensuring power supplies, ensuring heat removal functions, and severe accident responses. J-Power applied to the NRA on 16 December 2014 for review of the Ohma reactor[205] and on 9 September 2016, announced its decision to postpone its planned operating date for Ohma by two years until 2024, "due to longer-than-expected safety tests by the nuclear regulatory body."[206] This was the second major recent postponement, with its earlier plan to start operation in 2021.

Ohma is planned to operate with a 100-percent plutonium MOX core and is therefore of major strategic significance in terms of Japan's nuclear fuel policy, including the operation of the Rokkashomura reprocessing plant.[207]

Prospects for completion of construction and operation of Shimane-3 are directly linked to ongoing lawsuits, one by a thousand local citizens and another from the city of Hakodate, both of which are seeking cancellation of the project. The Hakodate city lawsuit is challenging

200 - JAIF, "Nuclear Power Plants in Japan–Shimane-3", 20 June 2017, see http://www.jaif.or.jp/en/npps/shimane-3/, accessed 30 April 2018.

201 - Sang-Baik Kim, Jan-Horst Keppler, "Case Studies On Project And Logistics Management In Nuclear New Built The ABWR Project at Shimane-3", Nuclear Development Division, Nuclear Energy Agency, OECD, as presented at the OECD Nuclear Energy Agency Workshop on Project and Logistics Management, Paris (France), 11 March 2014, see https://www.oecd-nea.org/ndd/workshops/pmnnb/presentations/docs/3.2.pdf, accessed 30 April 2018.

202 - *Asahi Shimbun*, "Process begins at Shimane nuclear plant to operate new reactor", 22 May 2018, see http://www.asahi.com/ajw/articles/AJ201805220043.html, accessed 15 July 2018.

203 - *Asahi Shimbun*, "Utility eyes NRA screening nod for new nuclear reactor in Shimane", 17 February 2018, see http://www.asahi.com/ajw/articles/AJ201802170020.html, accessed 30 April 2018.

204 - Ibidem.

205 - JAIF, "EPDC Submits Application for Compatibility Review for Ohma NPP", 18 December 2014, see http://www.jaif.or.jp/en/epdc-submits-application-for-compatibility-review-for-ohma-npp/, accessed 20 June 2017.

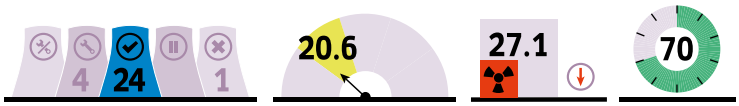
206 - *The Japan Times*, "J-Power delays plan to begin operating Oma nuclear plant until 2024", 9 September 2016, see http://www.japantimes.co.jp/news/2016/09/09/national/j-power-delays-plan-begin-operating-oma-nuclear-plant-2024, accessed 30 April 2018.

207 - Shaun Burnie, Frank Barnaby, et al., "Nuclear Proliferation in Plain Sight: Japan's Plutonium Fuel Cycle—A Technical and Economic Failure But a Strategic Success", *The Asia-Pacific Journal*, Vol.14, Issue 5, No.2, 1 March 2016, see https://apjjf.org/2016/05/Burnie.html, accessed 30 April 2018.

both the central government and J-Power in the first such lawsuit in Japan.[208] The citizen lawsuit injunction concluded its hearings in spring 2017. Submissions to the court noted that the final design, regulatory approval and construction of the nuclear island containment barrier for Ohma have yet to be completed.[209] On 19 March 2018, the Hakodate District Court ruled against the lawsuit brought by citizens, with the judgement that the regulatory review of the reactor remains to be concluded and that therefore "it's not reasonable for a court of law to conduct safety examinations without waiting for the NRA screenings... difficult to assess the particular risk of a severe accident right now", because it would be "uncertain, when the Oma plant will enter operation".[210] The Hakodate city lawsuit continues through 2018.

There remain major obstacles for both reactors, with little public information on the exact status and advancement of construction, and, in the case of Shimane-3, no communication of a planned grid-connection date, some construction work is reportedly ongoing at the Shimane site, for the time being. Therefore, WNISR maintains the current status of Shimane-3 as under construction, whereas Ohma was removed in 2017 from its listing of reactors under construction.

SOUTH KOREA FOCUS



On the Korean Peninsula, South Korea (Republic of Korea) operates 24 reactors. The country's oldest reactor, Kori-1 was shut down permanently on 18 June 2017.[211] 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 141.1 TWh in 2017—a drop of 8.6 percent from 154.31 TWh in 2016—supplying 27.1 percent of the country's electricity, and down from a maximum of 53.3 percent in 1987. As of April 2018, 11 reactors in Korea were shut-down for maintenance and inspection.[212] As of 1 July 2018, eight reactors remained shut down.[213] One of the issues that has led to delays in restarts of reactors has been the discovery of reactor

208 - *The Japan Times*, "Hakodate's Valid Nuclear Concern", 9 April 2014, see https://www.japantimes.co.jp/opinion/2014/04/09/editorials/hakodates-valid-nuclear-concern/, accessed 30 April 2018.

209 - Large & Associates, "On Aspects Relating To The Operational Nuclear Safety Of The Ōma Nuclear Power Plant, Aomori Insufficiencies And Incompleteness Of The Design, Construction And Nuclear Safety Case Submissions Available In The Public", 21 February 2017.

210 - *The Japan Times*, "Hakodate court rejects plea for injunction to halt construction of Oma MOX plant in Aomori", 19 March 2018, see https://www.japantimes.co.jp/news/2018/03/19/national/hakodate-court-rejects-plea-injunction-halt-construction-oma-mox-plant-aomori/#.WvLp69MvzOQ, accessed 30 April 2018.

211 - WNISR, "South Korea Marks Nuclear Policy Turn by Shutting Down Oldest Reactor", 19 June 2017, see https://www.worldnuclearreport.org/South-Korea-Marks-Nuclear-Policy-Turn-by-Shutting-Down-Oldest-Reactor.html, accessed 11 July 2018.

212 - Joori Roh, Sunil Nair "Status of South Korea's nuclear reactors", *Reuters*, 17 April 2018, see https://af.reuters.com/article/commoditiesNews/idAFL3N1RU20O, accessed 29 May 2018. Operating reactors as of 11 June 2018: Kori 2, Hanbit 3&4, Wolsong 1, Shin Wolsong 1, Hanul 4, Hanul 6, Shin-Kori 3.

213 - KHNP, "Real Time Operating Status", 1 July 2018, (in Korean), see http://www.khnp.co.kr/main.do, accessed 11 July 2018.

Containment Liner Plate (CLP) corrosion.[214] As a consequence, KHNP reactor maintenance period increased from 1,373 days in 2016 to 2,397 days in 2017.[215]

Four reactors are under construction, including Shin-Kori-4, whose start date was postponed from 2017, with commercial operation now planned for September 2018. Work resumed on the Shin-Kori-5 and -6 units in October 2017, following the result of a Public Consultation Committee and Citizens Panel. The decision on Shin-Kori-5 and -6 was followed in December 2017 with the 8th Basic Plan for Long-term Electricity supply and demand (BPE), which marks a major shift in overall energy policy, while confirming the gradual nuclear phase out road map announced in October 2017.[216] In the period to 2030, five new reactors will begin operation, while seven reactors would be taken offline as they reached 40 years operation. Nuclear power capacity would peak in 2022, before declining towards phase-out. At the same time, nine reactors have commenced operation since 2000, and five more are scheduled to begin operation in the period up to 2023. Thus, under current policy, nuclear power will remain a significant source of electricity generation well into mid-century.

Public Panel

President Moon Jae-in had committed to terminating the Shin-Kori-5 and -6 projects during his 2017 election campaign. But after being elected, he opted for decision-making based on public opinion and ordered the establishment of an independent commission charged with collecting public views and making a recommendation.[217] The government appointed a state commission to oversee the public consultation process, which included opinion gathering via telephone the views of 20,000 Koreans, and the creation of a 471-member Citizens Panel that would vote on the Shin-Kori project. The conclusion of the process, which involved public meetings and extensive media debate, was that on 20 October 2017 the Panel voted 59.5 percent for Shin-Kori-5 and 6 resumption of construction, and 40.5 percent opposed.[218]

The result of the public consultation process on the future of construction of Shin-Kori-5 and 6 was understandably hailed by the nuclear industry as victory.[219] Kim Kwang-ho, chairman of the Korean Nuclear Society, said: "I would like to express my sincere appreciation to all those who have supported nuclear power and have been active in the field, and who have supported

214 - The Nuclear Safety and Security Commission (NSSC) required inspection of corrosion at 19 nuclear units with containment liner plate (CLP), after the corrosion of CLP of Hanbit unit #2 was found in June 2016. As of February 2018, 17 out of 19 units had completed inspection, with 9 reactors found with corrosion. four reactors have completed repair and five units are under maintenance. Inspection of the remaining two reactors was scheduled to be completed by April 2018. See NSSC multiple reports on inspections, the most recent being Hanul-5 in May 2018, see NSSC, "Approval of re-operation after preventive maintenance", 16 May 2018, (in Korean), see http://www.nssc.go.kr/nssc/notice/report.jsp?mode=view&article_no=44264&pager.offset=0&board_no=2, accessed 6 June 2018.

215 - *Market Screener*, "Korea Electric Power : KEPCO recorded 5 trillion won of operating profit", *4-Traders*, 26 February 2018, see https://www.marketscreener.com/KOREA-ELECTRIC-POWER-CORP-6494969/news/Korea-Electric-Power-KEPCO-recorded-5-trillion-won-of-operating-profit--26055391/, accessed 6 June 2018.

216 - Se Young Jang, "South Korea's Nuclear Energy Debate", Carnegie Endowment for International Peace, 26 October 2017, see http://carnegieendowment.org/2017/10/26/south-korea-s-nuclear-energy-debate-pub-73561, accessed 11 June 2018.

217 - Jung Suk-yee, "Korean Government to Collect Public Opinions on Destiny of Nuclear Power Plants", *KoreaBusiness*, 28 June 2018, see http://www.businesskorea.co.kr/news/articleView.html?idxno=18484, accessed 29 May 2018.

218 - Lee Keun-young, Lee Jung-ae, "Shin-Kori 5 & 6 public task force recommends proceeding with construction", *Hankyoreh*, 21 October 2017, see http://english.hani.co.kr/arti/english_edition/e_national/815444.html, accessed 29 May 2018.

219 - *WNN*, "Citizens recommend completion of Korean units", 20 October 2017, see http://www.world-nuclear-news.org/NP-Citizens-recommend-completion-of-Korean-units-2010175.html, accessed 29 May 2018.

us from outside the nuclear power system";[220] while the World Nuclear Association's (WNA) Director General, Agneta Rising stated: "This is a very positive decision for South Korea. It will enable the South Korean nuclear sector to get on with reducing climate emissions and supporting national industrial competitiveness."[221]

While the final result did not provide President Moon with the result he had campaigned on, the panel established a first of its kind democratic process and legitimacy for national policy decisions,[222] with the process widely supported by civil-society organizations that for many years had sought greater transparency and public participation in decision-making.[223]

Given the history of nuclear policy decision-making in the Republic of Korea and the dominance of major corporations (Chaebol) with their vested interests, the approach of President Moon is nothing short of a revolution. The public process was in effect a rejection of nuclear power as a long-term energy source for Korea, in contrast to the interpretation of the WNA. The government secured a democratic mandate for the long-term phase out of nuclear power, when the Citizens Panel voted 53.2 percent for a reduction in nuclear power, with 35.5 percent supporting its maintenance at current levels, with only 9.7 percent supporting its expansion. With decisions on limiting nuclear reactors to a maximum of 40 years, effectively, nearly 90 percent of those polled support the phase out of nuclear power.

President Moon's office said the government, "respects the will of the public debate commission that made its recommendation after three months of deliberation...The government will do its utmost to implement follow-up measures without any disruption, based on the recommendation."[224]

New Energy Policy

The past year has seen confirmation of a strategic shift in overall energy policy following the election of President Moon Jae-in. In late December 2017, the Ministry of Trade, Industry and Energy confirmed that there would be a reduction in the use of coal and nuclear fuel, while expanding gas and renewables for power generation would be increased over the period 2017-2031. The 8th Basic Plan for long-term electricity supply and demand (BPE), which includes forecasts for power demand through to 2030, in terms of nuclear power would see capacity contract to 20.4 GW by 2030 from the current 21.8 GW.[225] However, during this period, nuclear capacity will peak at 28.5 GW in 2022, as five reactors (Shin-Kori-4, -5 and 6, and Shin-Hanul-1 and -2) enter service. A total of 21 reactors are planned to be in operation in 2030.

220 - Ibidem.

221 - Ibidem.

222 - Noh Ji-won, "Citizens leave Shin-Kori 5, 6 task force with positive impressions", *Hankyoreh*, 16 October 2017, see http://english.hani.co.kr/arti/english_edition/e_national/814689.html, accessed 29 May 2018.

223 - Citizens' Environmental Forum, "Progress and results of the public debate on Shin Gori 5,6", Korean Federation of Environmental Movements, 25 October 2017, see http://kfem.or.kr/?p=184636, accessed 29 May 2018; and Greenpeace Korea, "Restructuring of Shin-Kori 5 and 6 Units Can not Stop the Challenges of Energy Conversion", Press Release, 20 October 2017, (in Korean), see http://www.greenpeace.org/korea/news/press-release/climate-energy/2017/energy-transition-is-irreversible-wave-20171020/, accessed 29 May 2018.

224 - *Yonhap News*, "Cheong Wa Dae says it respects outcome of debate on nuclear reactors", 20 October 2017, see http://english.yonhapnews.co.kr/national/2017/10/20/0302000000AEN20171020005351315.html, accessed 30 May 2018.

225 - Ministry of Trade, Industry and Energy, "Ministry announces 8th Basic Plan for Electricity Supply and Demand", Press Release, 14 December 2017, see http://english.motie.go.kr/en/pc/pressreleases/bbs/bbsView.do?bbs_cd_n=2&bbs_seq_n=605, accessed 29 May 2018.

The new BPE, estimates peak power demand at 100 GW in 2030 (compared with 85 GW in 2017), of which 11.7 percent would be nuclear, then generating 23.5 percent of the country's electricity. In terms of renewables, the new BPE projects an increase of installed capacity (excluding large hydro and mainly on solar photovoltaics and wind) from 11.3 GW in 2017 to 58.5 GW in 2030, leading to a 20 percent market share of national generation capacity.

The significance of the new energy policy can be understood, when it is considered that over more than the three decades 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 Basic Plan) and KEPCO's 2011 proposed 43 GW of nuclear capacity. President Moon's opposition to nuclear energy reflects a wider societal shift triggered in the last seven years by the Fukushima Daiichi accident, but also subsequent falsification and corruption scandals at nuclear plants that forced the provisional shutdown of multiple reactors.[226] In October 2013, the government confirmed that 100 people, including a top former state utility official, had been indicted on corruption charges in relation to the falsification scandal (see previous WNISR editions for details).

Reflecting the shift in public and political opinion against nuclear power, in 2012, Park Won Soon, Mayor of Seoul, initiated a program entitled "One Less Nuclear Power Plant" with the official target by the end of 2014 to "save away" through energy efficiency and renewable energy roll-out the equivalent amount of energy generated by a nuclear power plant.[227] The target was achieved six months early and "Phase 2" of the Plan stipulates the saving/substitution of the equivalent of another two reactors by 2020. In 2013, the Seoul Metropolitan Government appointed a high-level Seoul International Energy Advisory Council (SIEAC), comprising leading international energy experts, to assist in the design of innovative clean energy policy.[228]

Thus the change in thinking about energy policy, entrenched over decades, did not happen overnight. Trade and Industry Minister Paik Un-Gyu, stated in early December 2017: "South Korea will abandon the decades-long nuclear-focused power mix plan… It will pursue the energy transition from nuclear and coal to renewables and LNG but will do that in a gradual manner."[229] The energy transition in South Korea is a work in progress, with much to criticize, including the lack of ambition on demand side management,[230] but it is a major shift in policy in Asia's third largest economy.

Construction Restart Delays and Cancelled Projects

The state commission charged with overseeing the public consultation process on the fate of Shin-Kori-5 and -6 made its recommendation to the Korean government on 20 October 2017

226 - KINS, "Safety Focus—CFSI (Counterfeit, Fraudulent, Suspect Item) Investigation", Undated, see http://www.kins.re.kr/en/ourwork/cfsi.jsp, accessed 11 July 2018.

227 - Roughly 2 MTOE (million tons of oil equivalent), calculated on the primary energy side.

228 - For a list of SIEAC Members and background see https://www.ieac.info. SIEAC is coordinated by Mycle Schneider.

229 - Ibidem.

230 - KFEM, "Review the 8th power supply basic plan to expand nuclear power, coal thermal power, Korean Federation of Environmental Movements, transmission line", 28 December 2018, see http://kfem.or.kr/?p=186791, accessed 29 May 2018.

for the resumption of construction, that had been suspended on 27 June 2017.[231] The Nuclear Safety & Security Commission (NSSC) had granted construction permits in 2016,[232] followed in September 2016 of a lawsuit against the permits, the first such legal action in South Korea.[233]

According to KHNP, official construction of Shin-Kori-5 ("first concrete") had started on 3 April 2017—but was announced only after President Moon's election—and that of Shin-Kori-6 is scheduled for September 2018. And as of 31 May 2018, "major construction status" for the overall project of both units is said to be 34.27 percent complete.[234]

Four reactors officially remain under construction, but with delays. On 8 February 2018, KHNP announced that there would be further delays to both the Shin-Kori-4 commissioning, as well as construction of the Shin-Hanul-1 and -2.[235] The delays were due to the reactors having to meet revised seismic safety inspections. Operation of Shin-Kori-4 had been postponed in 2017, with fueling scheduled for early 2018, and operation in September 2018. KHNP announced that as a result, the reactor may not meet its target operational date. For Shin-Hanul-1 and -2, where construction had continued through 2017, KHNP announced an 8-month delay from startup originally scheduled for April 2018 for unit 1 and February 2019 for unit 2. The new startup schedule is December 2018 and October 2019 respectively. All three of the new reactors passed previous safety inspections, however, on 15 November 2017, Korea's second largest recorded earthquake since records began in 1978, at 5.4 magnitude, struck in the south east of the country, 42 km from the Wolsung nuclear plant, 14 months after South Korea's largest earthquake, which occurred on 12 September 2016.[236] While there was no operational impact in 2017, the 2016 event temporarily shut four reactors.[237]

In regard to Shin-Kori-5, commercial operation at construction start was October 2021, it is now expected for March 2022, following the construction suspension.[238] In late May 2017, KHNP had suspended design work for Shin-Hanul-3 and -4, pending the governments new energy policy,[239] which in December 2017 confirmed their cancellation.

231 - Jung In-hwan, Kim Sung-hwan, "Construction to be suspended on fifth and sixth Shin-Kori nuclear reactors", Hankyoreh, 28 June 2017, see http://www.hani.co.kr/arti/english_edition/e_business/800632.html, accessed 11 July 2018.

232 - NSSC, "The 57th Meeting Grants Construction Permit for Shinkori Units 5 and 6", 23 June 2016, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=36864&pager.offset=160&board_no=501, accessed 29 May 2018.

233 - Greenpeace, "Greenpeace filed suit for cancellation of construction permit for Shin-Kori 5 and 6 with 559 citizens", Press Release, 12 September 2016, (in Korean), see http://www.greenpeace.org/korea/news/press-release/climate-energy/2016/starting-litigation-with-559-citizens-against-dangerous-approval-of-shinkori-5th-6th-nuclear-power-plants-20160912/, accessed 29 May 2018.

234 - KHNP, "Overview–Shin-Kori #5,6", 31 May 2018, see http://cms.khnp.co.kr/eng/content/545/main.do?mnCd=EN03020301, accessed 6 July 2018.

235 - *Yonhap News*, "Completion of new reactors delayed by quake-safety inspections", 8 February 2018, see http://english.yonhapnews.co.kr/search1/2603000000.html?cid=AEN20180208002800320, accessed 30 May 2018.

236 - *Hankyoreh*, "[Editorial] Latest earthquake shows importance of phasing out nuclear power on Korean Peninsula", 16 November 2017, see http://english.hani.co.kr/arti/english_edition/e_editorial/819393.html, accessed 29 May 2018; see also WNISR2017, "South Korea Focus" section for more background on the 2016 seismic event impacts.

237 - *NW*, "Four south Korean reactors still shut more than a month after earthquake", 27 October 2016.

238 - KHNP, "Nuclear Power Construction—Shin-Kori #5,6", 30 September 2017, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, accessed 18 October 2017.

239 - *Enerdata*, "Korea Hydro & Nuclear Power halts works for new Shin-Hanul nuclear reactors", *Asian Power*, 29 May 2017, see http://asian-power.com/project/news/korea-hydro-nuclear-power-halts-works-new-shin-hanul-nuclear-reactors, accessed 11 July 2018.

Following the closure of Kori-1, on 18 June 2017,[240] the seven reactors that are now planned to be decommissioned just prior to reaching their 40-year operating lifetime total 5.9 GW of capacity and are Wolsong-1 in 2022, Kori-2 in 2023, Kori-3 in 2024, Kori-4 and Hanbit-1 in 2025, and Hanbit-2 and Wolsong-2 in 2026. In the case of Wolsong-1, now South Korea's oldest operating reactor at almost 36 years, the government is considering an earlier closure than 2022. KHNP in October 2017 reported that it was conducting a legal assessment on the implications for early closure prior to 2022, based on the economic impact on the company.[241]

The government will take steps to shut the 682 MW Wolsong-1 "as soon as possible" before its extended 40-year lifespan ends in November 2022, it said in the Government's December 2017 Basic Plan.[242] The government has indicated that it would compensate KHNP citing the company's own data for a total of 244.1 billion won (US$230 million), whereas opposition lawmakers had cited figures as high as 995 billion won (US$920 million).

The government energy plan also confirms cancellation of six new reactor projects (all 1340 MW APR 1400 design): Shin-Hanul-3, Shin-Hanul-4, approved for construction; Cheonji-1, Cheonji-2 planned but not approved by government, and two others with no siting plan. The cancellation of these projects comes after successive governments had failed to secure new sites for plants, due to local opposition, including at Samcheok.[243]

Containment Liner Plate Corrosion

A total of six reactors as of July 2017 had been found to have Containment Liner Plate (CLP) metal thinning, some of which was due to corrosion.[244] The reactors were Hanbit-1, -2 and -4; Hanul-1; and Kori-3 and -4. CLP thinning is a long-known phenomenon, with any corrosion potentially changing the failure threshold under a challenging environmental or accident condition.

In June of 2016, the corrosion on the liner plate of Hanbit-2 was found during the in-service inspection. The Nuclear Safety & Security Commission (NSSC), ordered the licensee to perform the extensive examination for liner plates of all operating Pressurized Water Reactors (PWRs). The Korea Institute of Nuclear Safety reported that the discovery of the liner plate corrosion was confirmation of the limitations of in-service inspection.[245]

The extended shutdown of multiple reactors in Korea over the past year, has been used by those opposed to the new energy policy, to criticize the NSSC for prolonging inspections. The NSSC

240 - WNISR, "South Korea Marks Nuclear Policy Turn by Shutting Down Oldest Reactor", 19 June 2017, see https://www.worldnuclearreport.org/South-Korea-Marks-Nuclear-Policy-Turn-by-Shutting-Down-Oldest-Reactor.html, accessed 30 May 2018.

241 - Kim Eun-jung, "KHNP to review legality of early closure of Wolsong-1 reactor", *Yonhap News*, 31 October 2017, see http://english.yonhapnews.co.kr/search1/2603000000.html?cid=AEN20171031010651320, accessed 30 May 2018.

242 - *NW*, "South Korea government unveils roadmap for reducing nuclear power role", 21 December 2017.

243 - KFEM, "Samcheok, Youngdeok, Uljin : New nuclear power plant Democratic victory of local residents and citizens", 12 January 2018, see http://kfem.or.kr/?p=187206, accessed 29 May 2018.

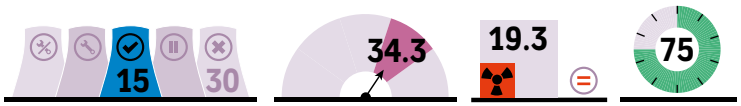
244 - Yonglak Paek, Sangyun Kim, et. al., "Introduction of Containment Liner Plate (CLP) Corrosion", Korea Institute of Nuclear Safety, South Korea Transactions of the Korean Nuclear Society Spring Meeting, 17-18 May 2018, see https://www.kns.org/files/pre_paper/39/18S-189%EB%B0%B1%EC%9A%A9%EB%9D%BD.pdf, accessed 9 July 2018.; see also NSSC, "NSSC Reveals the Inspection Results of the Backside Corrosion of the CLPs in the Containment Buildings and Future Plans" 27 July 2017.

245 - Ibidem.

responded robustly to these criticisms, noting: "When an urgent regulatory issue is found, such as the recent case of corrosion in the Containment Liner Plate, the NSSC inspects all reactor units to find out the cause of the same case and to ensure safety."[246] In May 2018, NSSC stated that in terms of reduced nuclear capacity over the past year "the operation rate fell to 71% last year and 58% last January because KHNP's facility maintenance has been prolonged due to the problems caused by their poor safety management practice [that] have been simultaneously found at all nuclear power plants."[247] The NSSC noted that average maintenance days per unit had increased significantly: 72 days in 2015; 89 days in 2016; 200 days in 2017. President Moon, appointed Dr Jungmin Kang as chair of the NSSC in December 2017.[248] Jungmin Kang was formerly senior research fellow at the Natural Resources Defense Council (NRDC) in Washington DC,[249] and a member of the International Panel on Fissile Materials (IPFM), based at Princeton University.[250]

In May 2018, the NSSC noted that six out of 24 reactors were under maintenance and inspection, two of which were being assessed for CLP corrosion/thinning—Wolsung-1 and Hanbit-4. Other units inspected had been found to have no CLP thinning, including Hanbit-5.[251]

UNITED KINGDOM FOCUS



In 2017, the United Kingdom operated 15 reactors, which provided 63.9 TWh or 19.3 percent of the country's electricity, down from 20.4 percent in 2016 and a maximum of 26.9 percent in 1997. The U.K.'s reactor fleet achieve an average load factor of 74.7 percent in 2017, more than 10 percent higher than their lifetime average. The average age of the U.K. fleet stands at 34.4 years (see Figure 26).

A total of 30 reactors have been permanently closed, 26 Magnox reactors, two fast reactors, an Advanced Gas-cooling Reactor (AGR) at Windscale and a Steam Generating Heavy Water Reactor (SGHWR) at Winfrith. The U.K.'s seven second-generation nuclear stations, each with two AGR, are now operating past the end of their 25-year design lives. However, owner, EDF Energy, is planning to further extend the lifetimes of all the AGRs for either seven years (Hinkley Point B, Hunterson B, Heysham-2 and Torness) or ten (Hartlepool, Heysham-1,

246 - NSSC, "The NSSC Approves Resumption of NPPs Only When Safety Is Guaranteed—Regular inspections proceed according to the procedures. And due to an safety issue found in one reactor unit, the NSSC is checking all nuclear power plants", 1 February 2018, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=44078&pager.offset=50&board_no=501, accessed 11 July 2018.

247 - NSSC, "Regarding the Chosul Ilbo op-ed titled "KEPCO in the red again, the nuclear phase-out policy is a nonsense that badly affects only citizens", 16 May 2018.

248 - *Yonhap News*, "President appoints new chief of nuclear safety commission", 29 December 2017, see http://english.yonhapnews.co.kr/news/2017/12/29/0200000000AEN20171229002700315.html, accessed 31 May 2018.

249 - NRDC, "Former NRDC Expert Sworn in as New Chief of South Korea's Nuclear Safety Commission", Press Release, Natural Resources Defense Council, 2 January 2018, see https://www.nrdc.org/media/2018/180102, accessed 31 May 2018.

250 - IPFM, "IPFM member Jungmin Kang appointed as chairman of South Korea's Nuclear Safety and Security Commission", International Panel on Fissile Materials, 15 January 2018, see http://fissilematerials.org/blog/2018/01/ipfm_member_jungmin_kang_.html, accessed 31 May 2018.

251 - NSSC, "The NSSC Approved Resumption of Hanul Unit 5 After Overhaul", 16 May 2018.

Dungeness B). The country's only PWR, at Sizewell B, is expected to operate until at least 2035.[252]

EDF Energy is largely owned by EDF (80 percent) with Centrica having a minority share (20 percent). However, Centrica are increasingly vocal in their desire to leave the nuclear business and, in February 2018, CEO Iain Conn said that "we would hope to divest of our shareholding in U.K. nuclear power by the end of 2020".[253]

Managing reactors as they age is a constant problem and the AGRs are no exception. In recent years the problem of cracking in the core's graphite bricks have raised concerns. In particular, keyway root cracks have been found at the Hunterston B reactor. This is of concern as this can lead to the degradation of the keying system, which are a vital component as they form the channels within the reactor, which house 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. This issue may well become a life limiting factor for the AGRs, as it is not possible to replace the graphite bricks. Questions have even been raised, if the reactor in question will be able to restart.[254]

In July 2012, call for tender was announced by the National Decommissioning Authority's—the Independent body established to decommissioning the state-owned nuclear facilities—to continue the decommissioning of the Magnox stations. This was said to be for contracts worth £6.1 billion (US$9.5 billion). Four companies bid, and the contract was awarded to Cavendish Fluor Partnership (CFP) in March 2014. However, the following month, Energy Solutions, which were part of the Reactor Site Solutions (RSS) consortium, which came second, brought a claim against the National Decommissioning Authority (NDA). The High Court ruled in favor of the RSS bid and, in March 2017, NDA reached a £85 million (US$103 million) agreement to settle the claim of Energy Solutions. Bechtel another unsuccessful bidder was later also awarded £12.5 million (US$16 million). The court amongst other things found that RSS and CFP did not always get the same marks for broadly comparable elements of their tenders. The Government announced in the fall of 2017 that it would terminate the contract of CFP early.[255]

In October 2017, the National Audit Office published a damning report on the decommissioning of the Magnox stations. This highlighted the 'fundamental failures in the Magnox contract' and raised questions about the NDA's 'understanding of procurement regulations and its ability to manage large, complex procurements'. The report was also critical of the Government's oversight arrangements.[256] The Government set up an independent inquiry to review the case, headed by Steve Holliday, which published its preliminary findings the same month of October 2017. This highlighted the findings of the Court and found that, the assessment procedure was over-complex, and that 64 percent of the scoring was attributed to costs, which was

252 - EDF, "Nuclear Lifetime Management", Undated, see https://www.edfenergy.com/energy/lifetime-management, accessed 7 May 2018.

253 - *NIW*, "Weekly Roundup", 23 March 2018.

254 - Natalie Muller, "UK's aging nuclear reactors have 'reached threshold limit", *Deutsche Welle*, see http://www.dw.com/en/uks-aging-nuclear-reactors-have-reached-threshold-limit/a-43675247, accessed 8 May 2018.

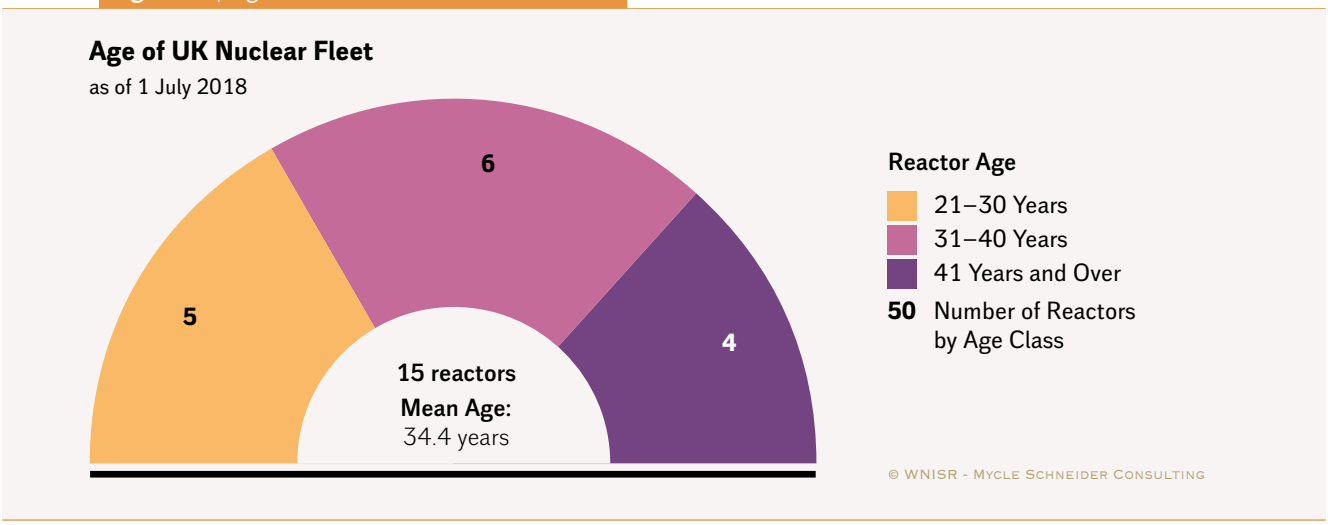
255 - Steve Holliday, "Magnox Inquiry—Interim Report", U.K. Government, 2017, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651019/Interim_Magnox_Report_-_Final_-_5th_October_2017___2_.pdf, accessed 15 May 2018.

256 - NAO, "The Nuclear Decommissioning Authority's Magnox contract", National Audit Office, see https://www.nao.org.uk/report/the-nuclear-decommissioning-authoritys-magnox-contract/ accessed 8 May 2018.

based on assumptions provided by the NDA and that the scoring mechanism for evaluating the bids was overly sensitive to change. The report made numerous recommendations including a broad ranging and basic call that 'the NDA's evaluation decision making process should be set out in advance and be strictly followed'.[257]

In 2006, then Prime Minister Tony Blair stated that nuclear issues were 'back on the agenda with a vengeance'.[258] In July 2011, the Government released the National Policy Statement (NPS) for Nuclear Power Generation.[259] 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 said it would not allow replacement of the Scotland located Torness and Hunterston plants once they are shut down.[260]

Figure 26 | Age Distribution of U.K. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2018

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[261] announced updates to the October 2013 provisional agreement of commercial terms of the deal for the £16 billion (US$20 billion) overnight cost of construction of Hinkley Point C (HPC).[262] The estimated price of construction has since risen and now stands at $£_{2015}$19.6 billion ($US\$_{2015}$25.3 billion), up from the $£_{2015}$18bn ($US\$_{2015}$23.2 billion) quoted in 2016. EDF says the £1.5bn (US$1.9 billion) increase announced in 2017 results mainly "from a better understanding of the design adaptated [adapted] to the requirements of the British regulators, the volume and sequencing of work on site and the gradu-

257 - Steve Holliday, "Magnox Inquiry—Interim Report", U.K. Government, 2017.

258 - *BBC*, "Blair backs nuclear power plans", 16 May 2006, see http://news.bbc.co.uk/1/hi/uk_politics/4987196.stm, accessed 7 May 2018.

259 - DECC, "National Policy Statement for Nuclear Power Generation", Department of Energy and Climate Change, U.K. Government, July 2011.

260 - Scottish Government, "Energy: Frequently Asked Questions", 25 June 2009, see http://www.gov.scot/Topics/Business-Industry/Energy/Facts/faqs, accessed 7 May 2018.

261 - DECC, "Hinkley Point C to power six million UK homes", Press Release, U.K. Government, 21 October 2015, see https://www.gov.uk/government/news/hinkley-point-c-to-power-six-million-uk-homes, accessed 7 May 2018.

262 - The 2013 and 2015 figures are all in 2012 money unless otherwise specified.

al implementation of supplier contracts". EDF maintains the official construction-start target-date as "mid-2019" and the "initial delivery objective for Unit 1 at the end of 2025".[263] However, EDF have acknowledged that pouring the first safety-related concrete for Hinkley Point C-1 in mid-2019 can only happen if "the final design, which is on a tight schedule, is completed by the end of 2018."[264]

When is Construction Work not Construction?

The International Atomic Energy Agency (IAEA) states that the construction start date is 'when first major placing of concrete for the base mat of the reactor building is made.'[265] WNISR applies that definition in its statistics.

There are mixed messages from EDF as to when or if construction has or will start at the Hinkley project, which include:

➔ The EDF energy web site (undated) states that "the final investment decision and the start of construction took place in the second half of 2016."

➔ In March 2017, EDF stated that "concrete has been poured for the power station galleries. The galleries are a network of connected tunnels which will carry cabling and pipes. They will be some of the first permanent structures on the site". EDF were then reported as stating that "construction of the building for the first reactor at HPC is scheduled to start in 2019 when concrete will be poured for the first time to make the reactor platform."[266]

➔ In September 2017, EDF Energy new-build director Humphrey Cadoux-Hudson said that EDF Energy plans the first nuclear concrete pour for the Unit 1 EPR in the fourth quarter of 2018 and hopes to conclude pouring the concrete by mid-2019.[267]

➔ On 22 February 2018, EDF Energy tweeted the following picture with the caption: "The enabling team celebrate the completion of the nuclear island foundations for the first of Hinkley's two reactors".

➔ In Spring 2018, EDF Energy reported that "construction is now beginning on the pre-stress gallery and the nuclear island foundation or common raft", "two key elements of the final nuclear power station structure". EDF Energy further clarify that "the nuclear island common raft and the pre-stressing gallery will form the foundation of reactor one and the building".[268]

263 - 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.

264 - Ibidem.

265 - IAEA, "PRIS—Glossary", Undated, see https://www.iaea.org/PRIS/Glossary.aspx, accessed 7 May 2018.

266 - EDF Energy, "EDF Energy sets out progress at Hinkley Point C new nuclear power station", 31 March 2017, see https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/news-views/progress-march-2017, accessed 7 May 2018.

267 - *NIW*, "Briefs—UK", 15 September 2017.

268 - EDF Energy, "Plugged in to Hinkley Point C – Reactor one takes shape", Spring 2018, see https://www.edfenergy.com/sites/default/files/edf_4731_plugged_in_spring_1.18_14_web_dps.pdf, accessed 3 July 2018.

"Nuclear island foundations"? "Base slab of the reactor building"?

➔ On 8 June 2018, an EDF Energy spokesperson told WNISR: "The confusion lies with the fact that the recognised 'construction start' has not yet been reached. In the HPC project, this date is termed 'J0' and is scheduled to be reached in June 2019" and "It was *not* the base slab of the reactor building. As I say, this is due to happen in June 2019." [Emphasis by EDF Energy][269]

➔ On 6 July 2018, a spokesman of the Office for Nuclear Regulation (ONR) told WNISR: "From a regulatory perspective, we operate a permissioning regime. We have given permission to commence the first nuclear safety concrete (in March 2017) (...) You would have to ask the site licensee about the 'official construction start' you quote, as [it] that is not from ONR."[270]

➔ Officially, the Hinkley Point C reactors are not listed as under-construction, despite, as of August 2016—two years ago—it was reported that EDF had spent already £2.5 billion (US$3.3 billion) on construction to date,[271] despite the "site construction director" stating in spring 2018 that "activity is ramping up with over 3,000 people now on-site... and over 100,000 tonnes of concrete has already been poured".[272]

By completing a large amount of the work before construction is formally begun, will EDF be able to claim a shortened construction timetable and be more likely to meet whatever startup date is finally announced, when construction *officially* begins. Given the construction delays in China, Finland and France this could be of primary importance for EDF.

269 - Gordon Bell, EDF Energy, spokesperson for Hinkley Point C, personal communication, email to Mycle Schneider, 8 June 2018.

270 - Jo deBank, ONR Communications Manager, personal communication, email to Mycle Schneider, 6 July 2018.

271 - Keith Rossiter, "Hinkley Point C: The story to date", *SouthWest Business*, 3 August 2016, see http://www.southwestbusiness.co.uk/regions/gloucestershire/hinkley-point-c--the-story-to-date-03082016080930/, accessed 7 May 2018.

272 - Rob Jordan, "Latest updates on the Hinkley Point C project and our continued work within the community from our site construction director", in EDF Energy, "Plugged in to Hinkley Point C – Reactor one takes shape", Spring 2018, see https://www.edfenergy.com/sites/default/files/edf_4731_plugged_in_spring_1.18_14_web_dps.pdf, accessed 3 July 2018.

The key points of the 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$115–120/MWh), with annual increases linked to the retail price index. The cost of this support scheme has rocketed, the U.K. National Audit Office suggesting that the additional 'top-up' payments—the difference between the wholesale price (as of early 2018 at about £50/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$201641.2 billion) in March 2016, due to falling wholesale electricity prices. However, this is the discounted estimate and that the undiscounted estimate is closer to £50 billion. The National Audit Office (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."[273] The NAO pointed to a key factor behind the Government's ongoing support for Hinkley, in that it is less about energy policy and more about the Government's perceived role in the world and its reputation, when they stated: "In September 2016, HM Treasury highlighted how the value-for-money case for HPC had weakened. But it concluded that the legal, reputational, investor and diplomatic ramifications of not proceeding meant it was, on balance, better to continue with the deal."[274] One could add a poorly understood military dimension (see Interdependencies Between Civil and Military Nuclear Infrastructures).

There was an expectation that HPCs 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) to help finance Hinkley and other capital-intensive projects.[275] This includes the partial sale of the French high voltage network (RTE) to the state bank Caisse des Dépôts in March 2017, which raised €4 billion (US$20184.6 billion).[276] and in November 2017 the sale of EDF Polska assets, including electricity and combined heat and power plants to Polska Grupa Energetyczna (PGE)for about €1.4 billion (US$$_{2018}$$1.6 billion).[277]

The incoming May administration finally approved the HPC project in September 2016, with the government retaining a 'special share', that would give it a veto over future ownership, if national security concerns arose.[278] The expected composition of the consortium owning the plant had changed from October 2013 to October 2015. In 2013, it was expected to comprise EDF (up to 50 percent), two Chinese companies, China General Nuclear Power Corporation (CGN) and China National Nuclear Corporation (CNNC) (up to 40 percent), and AREVA (up to 10 percent), with up to 15 percent still to be determined. In October 2015, the ef-

273 - Sir Amyas Morse KCB, "Hinkley Point C", Comptroller and Auditor General, Department for Business, Energy & Industrial Strategy, National Audit Office, 12 June 2017, see https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-C.pdf, accessed 7 May 2018.

274 - Ibidem.

275 - 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 7 May 2018.

276 - EDF, "EDF finalised the indirect sale of 49.9% of RTE assets to Caisse des Dépôts and CNP Assurances", 31 March 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-finalised-the-indirect-sale-of-49-9-of-rte-assets-to-caisse-des-depots-and-cnp-assurances, accessed 4 July 2018.

277 - EDF, "EDF finalizes the disposal of EDF Polska's assets to PGE", 14 November 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-finalizes-the-disposal-of-edf-polska-s-assets-to-pge, accessed 4 July 2018.

278 - Rowena Mason, 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 7 May 2018.

fective bankruptcy of AREVA made their contribution impossible, the Chinese stake had fallen to 33.5 percent and the other investors had not materialized leaving EDF with 66.5 percent. The October 2015 announcement mentioned only CGN leaving the impression CNNC had dropped out, but in May 2016, CNNC made it clear they didn't rule out participation in the 33.5 percent Chinese stake.[279]

One other new element was that the Chinese stake in the mooted follow-on Sizewell C project would be reduced to 20 percent, leaving EDF with 80 percent. Given the problems EDF is having financing Hinkley, this makes the Sizewell project appear implausible. However, EDF is allowing CGN to use the **Bradwell** site it had bought as back-up, if either the **Hinkley** or **Sizewell** sites proved not to be viable. CGN plans to build its own technology, the Hualong One (or HPR-1000) at this site, with EDF taking a 33.5 percent stake.[280] In January 2017, the U.K. Government requested that the regulator begin the Generic Design Assessment (GDA) of the HPR-1000 reactor. Work started later that month and is expected to be complete in 2021.[281]

The EDF-CGN consortium is not the only proposed reactor builder and NuGen, in June 2014, finalized a new ownership structure with Toshiba-Westinghouse (60 percent) and Engie (40 percent), as Iberdrola sold their shares. The group planned to build three Toshiba-Westinghouse-designed AP1000 reactors at the **Moorside** site, with units proposed to begin operating in 2024.[282] However, Westinghouse, after its financial collapse, filed for Chapter 11 bankruptcy protection in the USA in March 2017. This had a disastrous impact on the parent company Toshiba, when the extent of Westinghouse's problems came to light.[283] 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 them at the pre-determined price.[284] In late April 2017, the national press reported that Toshiba was preparing to mothball the project, warning suppliers of spending cuts and ordering seconded staff to return to their employees.[285] Amongst all this economic chaos, the U.K. Office of Nuclear Regulation had approved the AP1000 reactor design on 30 March 2017.[286]

Toshiba is now in talks with both, Korea's KEPCO, a nationally owned utility and reactor vendor, and CGN of China, as potential buyers of NuGen. Both companies, if they are to proceed, are likely to build their own reactors and not the EPR. In October 2017, the CEO of NuGen, said that they were expected to find a buyer by early 2018,[287] but KEPCO have put off a decision

279 - *The Times*, "Chinese give Hinkley Point nuclear project a boost", 9 May 2016.

280 - EDF Energy, "Agreements in place for construction of Hinkley Point C nuclear power station", EDF, Press Release, 21 October 2015, see https://uk.ambafrance.org/IMG/pdf/edf_press_release_hpc.pdf?6641/5060ea5271274dd6fc8234726c5962c9813fc14e., 7 May 2018.

281 - ONR, "Assessing new nuclear reactor designs—Generic Design Assessment Periodic Report: November 2016 – January 2017", Office for Nuclear Regulation, March 2017, see http://www.onr.org.uk/new-reactors/reports/gda-quarterly-report-nov16-jan17.pdf, accessed 7 May 2018.

282 - *NucNet*, "Toshiba Finalises Controlling Stake In UK Nuclear Company NuGen", 30 June 2014, see https://www.nucnet.org/all-the-news/2014/06/30/toshiba-finalises-controlling-stake-in-uk-nuclear-company-nugen, accessed 7 May 2018.

283 - 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 7 May 2018.

284 - Marcus Leroux, "French investor deals new blow to nuclear project", *The Times*, 5 April 2017.

285 - John Collingridge, "Toshiba mothballs Cumbrian nuclear power project", *Sunday Times*, 30 April 2017.

286 - 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 7 May 2018.

287 - *NIW*, "United Kingdom", 6 October 2017.

until the Autumn of 2018 and will only proceed if "a preliminary analysis concludes the project serves the national interests."[288]

The other company involved in proposed nuclear new-build is Horizon Nuclear, which was bought by the Japanese company Hitachi-GE from German utilities E.ON and RWE AG for an estimated price of £700 million (US$1.2 billion). The company has submitted its Advanced Boiling Water Reactor (ABWR) design for technical review, whilst making it clear that its continuation in the project will depend on the outcome of the negotiations with the Government.[289] The ABWR, planned for the **Wylfa** and **Oldbury** sites, passed the justification procedure in January 2015, and the Generic Design Assessment (GDA) was completed in December 2017.[290] In April 2017, Horizon Nuclear applied for a site license at the **Wylfa** location. If everything did go according to plan, the reactor would start up in 2025.[291] Hitachi is looking for partners in their project hoping to reduce their stake to 50 percent and, if no other investors can be found, the company plans to withdraw. This is because an internal review by the company has found that the cost of construction was likely to be US$27.5 billion, which is considered too big a risk for the company on its own.[292] It is also reported that the U.K. Government is prepared to make available £13.3bn (US$17.5 billion) in financial support for Hitachi [293]

In order to attract a partner, Hitachi is seeking clarification on the financial support that the Government is willing to facilitate or the extent to which the Government will invest. One option being considered is a tri-lateral partnership between Hitachi, and the U.K. and Japanese Governments.[294] Other companies, such as Korean KEPCO and Chinese CGN are also being approached.

In June 2018, the Government formally announced that it was considering taking an equity stake in the Wylfa project. This highlights the extent to which the Government, despite previous statements to the contrary, recognizes that, as *The Times* puts it, "nuclear power in really seems to be untenable without" state support. The Government seems to hope that by directly investing into the project, it will drive the strike price down to £70-78/MWh (US$92-103 MWh).[295]

The partners and potential partners for the NuGen and Horizon projects will face an uphill battle to get a similar level of CfD that was awarded to Hinkley. Criticism of the high support

288 - Phil Chaffee, "With Eyes on Saudi Arabia, Kepco Treads Water in the UK", *NIW*, 4 May 2018.

289 - Ambrose Evans-Pritchard, "Hitachi reluctant about UK nuclear reactor plan - Telegraph", *The Telegraph*, 14 April 2013, see https://www.telegraph.co.uk/finance/newsbysector/energy/9993564/Hitachi-reluctant-about-UK-nuclear-reactor-plan.html, accessed 7 May 2018.

290 - ONR, "Assessement of reactors—UK-ABWR—Design acceptance", December 2017, see http://www.onr.org.uk/new-reactors/uk-abwr/design-acceptance.htm, accessed 7 May 2018.

291 - *WNN*, "Horizon clears justification hurdle", 28 January 2015, see http://www.world-nuclear-news.org/NN-Horizon-clears-justification-hurdle-2801151.html, accessed 7 May 2018.

292 - Chartered Institute of Building, "Hitachi gets cold feet over UK's $27bn nuclear scheme", *Global Construction Review*, 30 April 2018, see http://www.globalconstructionreview.com/news/hitachi-gets-cold-feet-over-uks-27bn-nuclear-schem/, accessed 8 May 2018.

293 - Sarah Dickins, "UK 'set to finance' Wylfa nuclear plant", *BBC News*, 17 May 2018, see http://www.bbc.co.uk/news/uk-wales-44161097, accessed 18 May 2018.

294 - *Global Construction News*, "Hitachi Gets Cold Feet over UK's $27bn Nuclear Scheme", 2018.

295 - Phil Chaffee, "UK Launches Formal Talks for Wylfa Equity Stake", *NIW*, 8 June 2018.

cost for Hinkley and other nuclear projects has intensified with the awarding of tenders for offshore wind, with support prices of between £57.50-74.75 (US$80-101/MWh).[296]

The constant decline in energy *and* electricity consumption in the U.K. do not favor the economic case for nuclear new-build. Meanwhile, renewables' share of electricity generation reached 29.4 percent in 2017, outpacing nuclear power's contribution of 20.9 percent.[297] The rise in renewables is increasingly impacting the other generators and in its Summer Outlook for 2018, National Grid stated that, "there is a possibility that we may have to instruct inflexible generators to reduce their output, in order to balance supply and demand."[298]

Over the past decade the extraordinary cost of the U.K.'s proposed nuclear power program has become apparent to a wider academic community and public bodies. This is perhaps most clearly demonstrated by the change in the views of the Committee on Climate Change (CCC), an independent body established to advise the Government on meeting its climate change objectives. In 2011, they stated that "nuclear power currently appears to be the most cost-effective of the low carbon technologies".[299] However, in their most recent report, in June 2018, the CCC says that "if new nuclear projects were not to come forward, it is likely that renewables would be able to be deployed on shorter timescales and at lower cost".[300]

Leaving the European Atomic Energy Community - Brexatom

In June 2016, in a national referendum the U.K. population voted to leave the European Union. This has considerable implications for the energy and electricity sectors in the EU27 and the U.K.. However, what came as a surprise to some, was that the U.K. Government announced on 26 January 2017 in its European Union (Notification of Withdrawal) Bill, that the U.K. would also be leaving the Euratom Treaty.

The Treaty established the Atomic Energy Community (Euratom), whose primary function was to support the development of nuclear power and has remained, largely, unreformed and consequently a separate legal entity. The Treaty covers a wide range of responsibilities, including the verification of the non-proliferation of nuclear materials designated as non-military, and the setting of nuclear safety and radiation protection standards for workers, the public and the environment. To support the development of nuclear power, Euratom operates its own research and development program, has set up a nuclear specific loan facility and created a Supply Agency to ensure adequate access to nuclear materials, and is effectively controlling all nuclear material in the EU.

296 - *NIW*, "Briefs—UK", 15 September 2017.

297 - Department for Business, Energy & Industrial Strategy, "Energy Trends: Electricity", U.K. Government, 26 April 2018, see https://www.gov.uk/government/statistics/electricity-section-5-energy-trends, accessed 7 May 2018.

298 - National Grid, "Summer Outlook 2018", April 2018, see https://www.nationalgrid.com/sites/default/files/documents/14782_NG_Summer%20Outlook_2018.pdf, accessed 15 May 2018.

299 - CCC, "The Renewable Energy Review", Committee on Climate Change, May 2011, see https://www.theccc.org.uk/wp-content/uploads/2011/05/The-renewable-energy-review_Printout.pdf, accessed 4 July 2018.

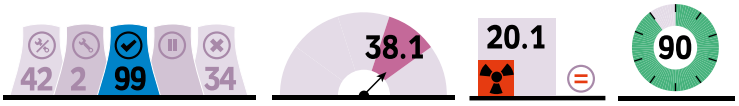
300 - CCC, "Reducing UK emissions 2018 Progress Report to Parliament", June 2018, see https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf, accessed 4 July 2018.

In order to start replacing the safeguards functions undertaken by Euratom, in June 2018, the IAEA agreed a Voluntary Offer Agreement and an Additional Protocol for the U.K.[301] under which the IAEA applies safeguards to nuclear materials in facilities that the U.K. has voluntarily offered (as an official nuclear weapons state). The U.K. Parliament also passed in June 2018 a Nuclear Safeguards Bill, which will enable the U.K. regulator to take over responsibility for safeguards inspections, that are then reported directly to the IAEA.[302]

The U.K. has also begun negotiating with third countries, new Nuclear Co-operation Agreements (NCA), to replace those undertaken by the EU. In May 2018, President Trump signed an NCA with the U.K. that now has to be approved by Congress.[303]

The U.K.'s departure from the EU and Euratom Treaty will also have a political impact on the nuclear sector within the EU27, as the U.K. has been one of its most active supporters in the EU. Furthermore, the complications around Brexatom put a spotlight onto the Euratom Treaty, whose legal status and many of its functions are out of step with the modern EU and may once again lead to calls for its abolition.

UNITED STATES FOCUS



"I don't think we're building any more nuclear plants in the United States. I don't think it's ever going to happen... They are too expensive to construct, relative to the world in which we now live."

William Von Hoene
Senior Vice President and Chief Strategy Officer, Exelon
May 2018[304]

With 99 commercial reactors currently operating as of 1 July 2018, the U.S. possesses the largest nuclear fleet in the world. The fallout from the bankruptcy of historic builder Westinghouse in 2017, and the resulting termination of the construction of two AP1000 reactors at V.C. Summer

301 - BEIS, "Quarterly update to Parliament on the government's progress on the UK's exit from the Euratom Treaty", Department for Business, Energy and Industrial Strategy, U.K. Government, 28 June 2018, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/720496/Second_quarterly_report_to_Parliament_on_Euratom_progress__final___1_.pdf, accessed 12 August 2018.

302 - U.K. Parliament, "Nuclear Safeguards Act 2018", 26 June 2018, see https://services.parliament.uk/bills/2017-19/nuclearsafeguards.html, accessed 4 July 2018.

303 - President Trump, "Presidential Message to the Congress of the United States", The White House, 7 May 2018, see https://www.whitehouse.gov/briefings-statements/presidential-message-congress-united-states-4/, accessed 4 July 2018.

304 - With 23 operational reactors, Exelon is the US' largest nuclear operator. Steven Dolley, "No new nuclear units will be built in US due to high cost: Exelon official", S&P Global, Platts, 18 April 2018, see https://www.platts.com/latest-news/electric-power/washington/no-new-nuclear-units-will-be-built-in-us-due-26938511, accessed 22 May 2018.

in South Carolina on 31 July 2017,[305] continued through the year with major conflicts in the state on the billions of dollars of ratepayers' money lost to the abandoned project. At the same time a highly contentious decision was taken to continue construction of two other AP1000's at Vogtle in Georgia on 21 December 2017, following decisions at the state and federal level aimed at providing additional financial support.[306]

Meanwhile attempts to secure state and federal financial support for operating nuclear plants have continued to varying degrees of success. As of 2018, subsidies will be provided to eight nuclear plants in the U.S., in the form of Zero Emission Credits (ZEC): Nine Mile Point, FitzPatrick and Ginna in New York; Clinton and Quad Cities in Illinois; Salem and Hope Creek in New Jersey; and Palisades in Michigan.[307] Legal challenges against ZEC nuclear legislation from consumers, NGO's and energy companies are ongoing in all of these states.

The decision to close the Palisades reactor scheduled for October 2018 was reversed by Entergy in September 2017, and the plant is now expected continue operating until 2022.[308]

> *"it is inevitable that the size of the U.S. nuclear fleet will continue to decline for the foreseeable future"*

The Nuclear Energy Institute (NEI), the advocacy organization for the U.S. nuclear industry, has continued to lobby for financial support for nuclear plants, while the Department of Energy (DOE) has sought to pressurize the Federal Energy Regulatory Commission (FERC) into rule making that would aid nuclear utilities. The NEI warning in 2016[309] of "15-to-20 plants at risk of shut-down over the next five-to-10 years" continues to remain valid into 2018.

At the same time, several utilities reversed decisions to close reactors after they secured state level financial support. Therefore, while it is inevitable that the size of the U.S. nuclear fleet will continue to decline for the foreseeable future, the decline could be slowed down by directly subsidizing threatened operating plants.

The U.S. reactor fleet provided 805 TWh in 2017, as in 2016, below the record year of 2010 with 807.1 TWh. Consequently, the load factor remained almost stable at a high level of 89.8 percent, significantly above the modest lifetime load factor of 75.3 percent. Nuclear plants provided 20.1 percent of U.S. electricity in 2017, about 2.5 percentage points below the highest nuclear share of 22.5 percent, reached in 1995.

305 - 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 3 August 2017.

306 - Anastaciah Ondieki, "Georgia PSC votes to continue construction at Plant Vogtle", AJC, 21 December 2017, see https://www.ajc.com/news/local-govt--politics/georgia-psc-votes-continue-construction-plant-vogtle/Tu0ja76KWtR3YGlhaFLTeM, accessed 3 May 2018; and U.S.DOE, "Secretary Perry Announces Conditional Commitment to Support Continued Construction of Vogtle Advanced Nuclear Energy Project", Department of Energy, 29 September 2017, see https://www.energy.gov/articles/secretary-perry-announces-conditional-commitment-support-continued-construction-vogtle, accessed 5 May 2018.

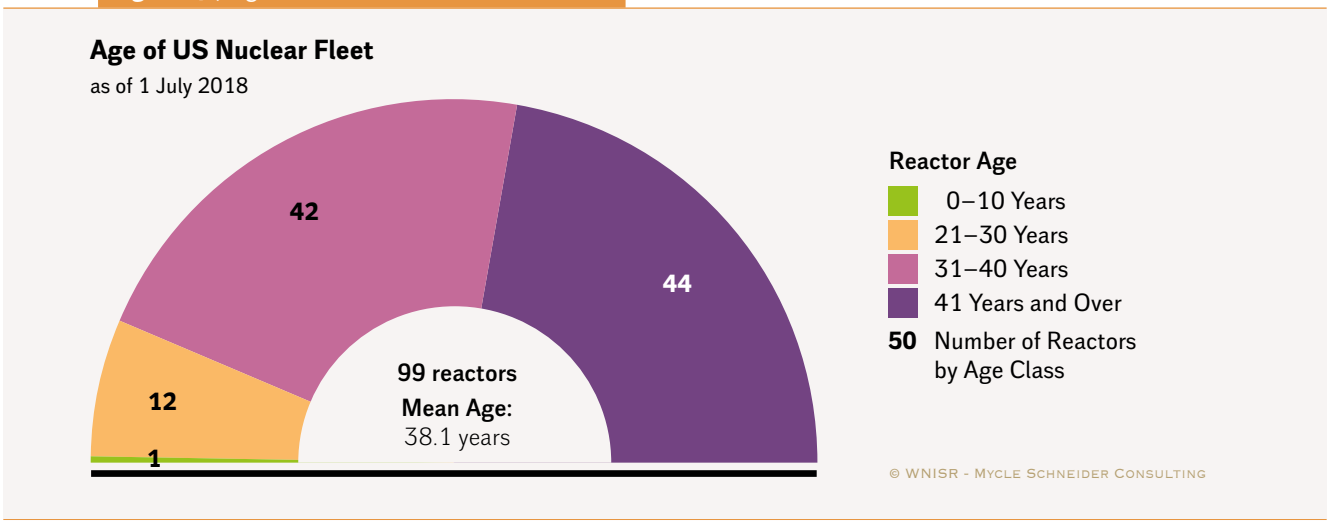
307 - Geoffrey Haratyk, "Early Nuclear Retirements in Deregulated U.S. Markets: Causes, Implications and Policy Options", Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology, March 2017, see https://assets.documentcloud.org/documents/3723775/MIT-Early-Nuclear-Retirement-3-2017.pdf, accessed 17 May 2018.

308 - Entergy, "Entergy to Continue Operating Palisades Power Plant Until Spring 2022", 28 September 2018, see http://www.palisadespower.com/entergy-to-continue-operating-palisades-power-plant-until-spring-2022/, accessed 20 May 2018.

309 - Wayne Barber, "NEI warns more nuclear power plant retirements on the way", Electric Light & Power, 23 May 2016, see http://www.elp.com/articles/2016/05/nei-warns-more-nuclear-power-plant-retirements-on-the-way.html, accessed 6 August 2017.

With only two reactors under construction and only one new reactor started up in 20 years, the U.S. reactor fleet continues to age, with a mid-2018 average of 38.1 years, amongst the oldest in the world: 44 units have operated for more than 40 years (see Figure 27).[310]

Figure 27 | Age Distribution of U.S. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2018

The newest reactor in the U.S. reactor fleet, the Tennessee Valley Authority (TVA) Watts Bar unit 2, which only began operations on 19 October 2016,[311] restarted on 1 August 2017,[312] after a 19-week shutdown following a structural failure in the main condenser.[313]

In the year to December 2017, the Nuclear Regulatory Commission (NRC) issued a single 20-year license renewal for one nuclear plant, the South Texas Project units 1&2.[314] Significantly, one nuclear plant applied for a subsequent license renewal, which if granted would see the reactors operate for an additional 20 years beyond their current sixty year license.[315] The Turkey Point units 3&4, owned by Florida Light & Power, began operation in November 1972 and June 1973 respectively, and are the first reactors to apply for an NRC operational license beyond 60 years.[316] In December 2015, the NRC put out a draft document describing "aging

310 - U.S. EIA, "Electricity Data Browser—Net Generation, monthly", U.S. Energy Information Administration, see https://www.eia.gov/electricity/data/browser/, accessed 3 May 2017.

311 - TVA, "Watts Bar Unit 2 Complete and Commercial", Tennessee Valley Authority, 19 October 2016, see https://www.tva.com/Newsroom/Watts-Bar-2-Project, accessed 3 May 2017; and WNISR, "Watts Bar-2 (US): Grid Connection 43 Years After Construction Start—Shutdown 2 Days Later", 8 June 2016, see https://www.worldnuclearreport.org/Watts-Bar-2-US-Grid-Connection-43-Years-After-Construction-Start-Shutdown-2.html, accessed 24 May 2017.

312 - *Dave Flessner, "TVA restarts Watts Bar Unit 2 after four months of repairs", Times Free Press*, 1 August 2017, see http://www.timesfreepress.com/news/breakingnews/story/2017/aug/01/tva-restarts-watts-bar/441309/, accessed 5 May 2018.

313 - U.S.NRC, "Preliminary notification of even or unusual Occurrence PNO-II-17-002— Shutdown due to condenser failure", 23 March 2017, see https://www.nrc.gov/docs/ML1708/ML17082A621.pdf, accessed 24 May 2017.

314 - U.S.NRC, "South Texas Project, Units 1 and 2 – License Renewal Application", Updated, 28 September 2017, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/south-texas-project.html, accessed 5 May 2018.

315 - NRC, "Turkey Point Nuclear Plant, Units 3 & 4 – Subsequent License Renewal Application", Updated 3 May 2018, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/turkey-point-subsequent.html, accessed 5 May 2018.

316 - Florida Light and Power, "Turkey Point Nuclear Plant Units 3 and 4 Subsequent License Renewal Application Revision 1", Docket Nos. 50-250 and 50-251 L-2018-082 Enclosure 3, U.S.NRC, April 2018, see https://www.nrc.gov/docs/ML1811/ML18113A146.pdf, accessed 5 May 2018.

management programs" that might allow the NRC to grant nuclear power plants operating licenses for "up to 80 years".[317]

The NRC is expecting one further subsequent license renewal application in 2018 for the Peach Bottom Atomic Power Station units 2&3.[318]

The 20-year license renewal application for the Diablo Canyon units 1&2 was withdrawn by the licensee Pacific Gas & Electric on 7 March 2018.[319] The two units will continue operating until their current operating licenses expire (2 November 2024, for Unit 1, and 20 August 2025, for Unit 2.)

As of 1 July 2018, 86 of the 99 operating U.S. units had received a license extension with a further four applications for five reactors under review.[320]

Securing Financing to Prevent Shutdowns

2017, as in the previous year, witnessed continuing efforts by nuclear utilities, as well as by the Trump administration, to find mechanisms to secure financial support for the U.S. ailing reactor fleet. The NRC's exploration of a path to further extend nuclear reactors operating lifetimes is in direct contradiction to the signals from the electricity markets, which has been to rather accelerate shutting down old reactors.

The crisis facing nuclear plants was made clear in a March 2017 Massachusetts Institute of Technology (MIT) study which reported that two thirds of the nuclear power capacity is unprofitable through 2019 on the basis that current electricity price trajectory remains with no change in operating costs. As they concluded:

> We estimate that supporting the existing nuclear assets is a very cost-effective mean to lower carbon emissions until more efficient carbon-free technologies develop.
>
> In this market environment characterized by persistently low natural gas prices and stagnant electricity demand, the analysis shows that about two thirds of the 100 GW nuclear capacity are uncompetitive over the next few years under the current trajectory. Among those in merchant deregulated markets, 21 GW are retiring, or are at high risk of retiring prematurely.[321]

MIT reported that thirty-five nuclear plants, with a total capacity of 58 GW are unprofitable, with 14 GW located in merchant deregulated electricity markets (not including the 6 GW already announced for retirement in the coming years). In regulated markets, 44 GW are "uncom-

317 - U.S.NRC, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report – Draft Report for Comment (NUREG-2191, Volume 1)", 15 December 2015, see https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2191/v1/, accessed 5 May 2018.

318 - U.S.NRC, "Peach Bottom Atomic Power Station, Units 2 and 3 License Renewal Exelon Nuclear Renewed Facility Operating License", Nos. DPR-44 and DPR-56, U.S.NRC Docket Nos. 50277 and 50278", 7 June 2016, see https://www.nrc.gov/docs/ML1615/ML16159A115.pdf, accessed 5 May 2018.

319 - U.S.NRC, "Status of Initial License Renewal Applications and Industry Initiatives", Updated 4 May 2018, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 5 May 2018.

320 - Ibidem.

321 - Geoffrey Haratyk, "Early Nuclear Retirements in Deregulated U.S. Markets: Causes, Implications and Policy Options", Center for Energy and Environmental Policy Research, MIT, March 2017, see https://assets.documentcloud.org/documents/3723775/MIT-Early-Nuclear-Retirement-3-2017.pdf, accessed 17 May 2018. The study reported that Prairie Island and Monticello in Minnesota appear to be the least profitable plants by far, due to low wholesale price in North-West and low capacity factor (80-82%), and with most Southeast plants show(ing) a negative outlook due to the larger cost of production of regulated plants versus merchant plants.

petitive" in the sense that their cost of production is greater than the estimated wholesale price of electricity.

In its "Annual Briefing for the Financial Community" delivered on 12 April 2018, Maria G. Korsnick, the Nuclear Energy Institute's (NEI) president and chief executive warned:

> Six reactors closed in the last five years, and we lose 38 million megawatt-hours of emissions-free electricity every year. Plant owners have announced their intention to close twelve more in the coming years. If nothing is done to save these plants, the impacts will be devastating. Thousands of jobs will be lost across the country.[322]

The industry has opted to frame the need to maintain nuclear power through federal financial support in terms of its importance to the nation's infrastructure, including grid stability, as well as jobs, clean air, and tax revenue, and with deliberately less emphasis on the claimed climate mitigation role of nuclear power. Given the current U.S. administration, this would appear a logical approach, but it has been found to be not based on the reality of the U.S. electricity network. With the growth of renewables across the U.S. the future is not going to get any easier for nuclear generators, as a 2018 Lawrence Berkeley study observed that the increasing penetrations of variable renewable energy (VRE) can affect wholesale electricity price patterns, one consequence being that the "greater amounts of VRE may accelerate nuclear retirements at the regional level."[323]

"greater amounts of VRE may accelerate nuclear retirements at the regional level."

In October 2017, the Department of Energy (DOE) under Section 403 of the DoE Organization Act proposed a rule to be implemented by the Federal Energy Regulatory Commission (FERC). Described as 'Grid Resiliency Pricing Rule', the DOE reported that wholesale power markets do not adequately price the resiliency attributes of "fuel-secure" power plants. The DOE specifically cited, "significant retirements of baseload generation, particularly coal and nuclear resources." The DOE proposed that any such plants that are located within organized electric markets and that are not subject to cost-of-service rate regulation by any State or local authority, i.e. "merchant" plants, should receive full cost recovery along with a return on equity.[324]

The proposed rule pitted coal and nuclear utilities, who were generally in favor, against the gas and renewable energy industries. In the following weeks, the DOE received hundreds of comments filed by entities that covered the entire energy-industry landscape across all regions under FERC's jurisdiction. Comments were submitted by individuals, Congressional leaders, former FERC Commissioners, electric utilities, power marketers, merchant generators, fuel suppliers, regional entities, governmental agencies and industry trade organizations, with a

322 - Maria Korsnick, "Financial Community Annual Briefing 2018—Choices in Akron, Trenton and Riyadh", NEI, 12 April 2018, see https://www.nei.org/CorporateSite/media/filefolder/news/speeches/nei-annual-briefing-for-financial-community-speech-20180412.pdf, accessed 5 May 2018.

323 - Joachim Seel et al., "Impacts of High Variable Renewable Energy Futures on Wholesale Electricity Prices, and on Electric-Sector Decision Making", Electricity Markets and Policy Group, Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory, May 2018, see http://eta-publications.lbl.gov/sites/default/files/report_pdf_0.pdf, accessed 20 May 2018.

324 - Advanced Energy Economy, The American Petroleum Institute, The American Wind Energy Association, The Electric Power Supply Association, The Interstate Natural Gas Association of America, The Natural Gas Supply Association, Letter to Secretary Rick Perry, 7 May 2018, see https://info.aee.net/hubfs/Trade%20Associations%20Letter%20and%20Legal%20Analysis%205-7-18.pdf, accessed 9 May 2018.

substantial majority of those entities submitting substantive pleadings being critical of the preferential payments proposed in the DOE.[325]

In evidence to the DOE submitted in November 2017, NERC (the North American Electric Reliability Organization) cited from its 2017 Long-Term Reliability Assessment that an additional eight nuclear units in the U.S. are planning retirement by 2025.[326]

The PJM Interconnection [Pennsylvania-New Jersey-Maryland Interconnection LLC], which is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia, challenged both the proposed DOE rule making and the evidence put forward by industry, noting:

> The facts do not support the DOE's proposal to provide cost of service rates to nuclear and coal generation... the DOE Proposal would undermine competitive markets. For these reasons, the Commission should reject the DOE Proposal.[327]

In January 2018, FERC rejected DOE's proposal unanimously. FERC emphasized its historic commitment to both reliability and markets, observing that it "has been able to focus on both without compromising its commitment to either."[328] FERC rejected the notion that the retirement of certain generators in regional transmission organization and independent system operator (RTO/ISO) markets meant that the prices in those markets were unjust and unreasonable. FERC also concluded that DOE failed to establish that its own proposal was just, reasonable and legal.

"As with all transitions, there have been market winners and losers."

In a conclusion that encapsulates the near-term threat to the viability of a large share of the U.S. nuclear fleet (see also Table 6), FERC stated:

> In the 21st century, against the backdrop of wholesale markets, the pace of technological change in energy has accelerated, resulting in a rapid transformation of the nation's resource mix. This has been driven by (1) the growth in the availability and affordability of domestic natural gas and its increased use for electric generation, (2) the rapid development and deployment of wind, solar, storage, and demand-side technologies, both central and distributed, and (3) a changing understanding of the environmental consequences of energy use,

325 - United States of America before the Federal Energy Regulatory Commission, "Grid Reliability and Resiliency Pricing: Joint Industry Reply comments opposing the DOE proposal", Docket No. RM18-1-000, 7 November 2017, see https://info.aee.net/hubfs/Joint_Reply_Comments_on_Reform_11.7.17.pdf?t=1510086093096&_hsenc=p2ANqtz-9z9y5jRyyCR7fqpTNDcFOS0qluV1bxBA7zjmqMLmJF4wABoScFGOpMlh3oCXgh7eludVHWg7wUeulLVHIFyOmI3CmP1u1hLMtzRK9lIhxCGe4vuPg&_hsmi=58189438, accessed 9 May 2018.

326 - NERC, "2017 Long-Term Reliability Assessment", North America Reliability Corporation, 13 December 2017, see https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_12132017_Final.pdf, accessed 9 May 2018.

327 - Monitoring Analytics, "Grid Reliability and Resilience Pricing: Reply Comments Of The Independent Market Monitor For Pjm", United States Of America Before The Federal Energy Regulatory Commission, , Docket No. RM18-1-000, see http://www.monitoringanalytics.com/reports/Reports/2017/IMM_Reply_Comments_Docket_No_RM18-1_20171107.pdf, accessed 9 May 2018.

328 - FERC, "Order Terminating Rulemaking Proceeding, Initiating New Proceeding, And Establishing Additional Procedures" Grid Reliability and Resilience Pricing Grid Resilience in Regional Transmission Organizations and Independent System Operators, Docket Nos. RM18-1-000 AD18-7-000, 8 January 2018, see https://www.ferc.gov/CalendarFiles/20180108161614-RM18-1-000.pdf, accessed 5 May 2018.

> especially climate change, driving state and federal policy and customer choices... As with all transitions, there have been market winners and losers as new technologies have brought competitive pressures to bear on existing resources.[329]

The decision of FERC did not end the efforts of utilities to secure additional federal financial support. FERC in its decision had called for further assessments of grid resilience. This was seized upon by NEI who in May 2018 filed with NERC a call for it "to move quickly to define, foster and retain resiliency on the country's electricity grid before further nuclear generating capacity is lost through premature plant retirements."[330]

In the aftermath of FERC's decision, FirstEnergy Solutions, petitioned the DOE for federal use of emergency authority to provide a long-term subsidy for aging and uneconomic power plants that would otherwise retire.[331] PJM's response was to dismiss warnings of shortages, stating that the "PJM system has adequate power supplies and healthy reserves in operation today; and resources are more diverse than they have ever been...The potential for the retirements has been discussed publicly for some time. In anticipation, PJM took a preliminary look at the effect of the retirements on the system. We found that the system would remain reliable. We have adequate amounts of generation available."[332]

On 1 June 2018, a leaked DOE memo obtained by Bloomberg detailed how the Trump administration was considering using emergency powers under the Federal Power Act and/or the Defense Production Act to prevent early closure of nuclear and coal plants, as well as establishing a "Strategic Electric Generation Reserve".[333] According to the draft, such intervention would be justified on the basis that "Federal action is necessary to stop the further premature retirements of fuel-secure generation capacity."[334] The Federal Power Act gives the Secretary of Energy the authority to issue must-run orders to individual plants in the case of an emergency, exempting them from emissions regulations and insulating them from market forces. The memo refers to "requiring regional grid operators to buy power from select coal and nuclear plants for two years, using executive authority under emergency provisions of the Federal Power Act and the Defense Production Act."

The Chair of FERC in Congressional testimony 19 June 2018 noted that if the DOE were to act using that law, regional grid operators would work with the plants to arrange a payment agreement. If the parties could not reach an agreement, FERC then would get involved to figure out a "just and reasonable" rate. "We don't know what's going to happen," McIntyre said. "It's im-

329 - Ibidem.

330 - WNA, "Nuclear for US grid resilience and climate", World Nuclear Association, 10 May 2018, see http://www.world-nuclear-news.org/NP-Nuclear-for-US-grid-resilience-and-climate-1005187.html, accessed 11 May 2018.

331 - Cleveland.com"FirstEnergy Solutions asks DOE to help save its old power plants", Updated 31 March 2018, see http://www.cleveland.com/business/index.ssf/2018/03/firstenergy_asks_doe_for_emerg.html, accessed 8 May 2018.

332 - Ibidem.

333 - Jennifer A Dlouhy, "Trump Prepares Lifeline for Money-Losing Coal Plants", *Bloomberg*, 1 June 2018, see https://www.bloomberg.com/news/articles/2018-06-01/trump-said-to-grant-lifeline-to-money-losing-coal-power-plants-jhv94ghl, accessed 11 July 2018.

334 - U.S.DOE, "Draft-5/29/18", 29 May 2018, U.S. Department of Energy, see https://www.documentcloud.org/documents/4491203-Grid-Memo.html, accessed 11 July 2018.

portant to remind ourselves nothing has happened yet. If it does [happen], it could well result in the matter coming to us for what looks to us to be fairly straightforward rate proceeding."[335]

In February 2018, Assistant DOE Secretary Bruce Walker, head of the Office of Electricity Delivery and Energy Reliability, had stated that neither he nor Perry are considering such actions. "We would never use a 202 to stave off an economic issue," he said. "That's not what it's for."[336]

While welcomed by the nuclear industry,[337] the disclosure of DOE / Trump administration plans led to widespread condemnation from energy interests, analysts and NGOs.[338] "Not even the president can unilaterally rewrite the Federal Power Act so anything that seeks to override [the Federal Energy Regulatory Commission's] role and tariffs on how plants are dispatched and paid would be challenged on that basis, among others," said John Shelk, president and CEO of the Electric Power Supply Association, which represents independent power generators.[339] While the Advanced Energy Economy association called the plan to federalize the electric power system, "an exercise in crony capitalism taken solely for the benefit of a bankrupt power plant owner and its coal supplier. It would be a command-and-control mechanism that fundamentally disrupts and undermines the competitive electricity markets that have improved our electricity system's reliability, resilience, and affordability, while fostering innovation" and warned that the plan, "is wholly unprecedented and legally indefensible. We will fight this needless energy tax on businesses and families with every tool at our disposal."[340] The Natural Resources Defense Council (NRDC) concluded that, "DOE seems determined to find a way to placate coal and nuclear companies, no matter the cost to consumers or lack of actual national security needs. To be clear, any bailout must be paid for in *some* way—Americans will pay either through their utility bills or by the misappropriation of national security funds, meaning taxpayer dollars."[341] The Energy Innovation think tank warned that, "The Trump administration would have customers shoulder billions of dollars in costs to support a withering industry that has failed to remain competitive with the abundance of new natural gas, cheap renewable resources, flat demand growth, and growing energy efficiency... What's being discussed here is disgraceful and threatens to undermine the very foundation of competitive elec-

335 - Josh Siegel, "Rick Perry will make 'right decision' on coal and nuke bailout, FERC chairman says", *Washington Examiner*, 19 June 2018, see https://www.washingtonexaminer.com/policy/energy/rick-perry-will-make-right-decision-on-coal-and-nuke-bailout-ferc-chairman-says, accessed 11 July 2018.

336 - Gavin Bade, "DOE 'would never use' emergency order for uneconomic plants, Walker says", *Utility Dive*, 20 February 2018, see https://www.utilitydive.com/news/doe-would-never-use-emergency-order-for-uneconomic-plants-walker-says-1/517455/, accessed 9 July 2018.

337 - *Platts Nuclear News Flashes*, "Nuclear industry applauds Trump administration proposal to aid at-risk coal, nuclear units", *S&P, 1 June 2018*.

338 - John Moore, Gillian Giannetti "The Coal and Nuclear Bailout Memo: Recycled Idea, New Hat!", NRDC, 1 June 2018, see https://www.nrdc.org/experts/john-moore/coal-and-nuclear-bailout-memo-recycled-idea-new-hat, accessed 11 July 2018; and Jeff St. John, "Breaking Down the Opposition to DOE's Emergency Coal and Nuclear Bailout Plan", *Greentech Media*, 1 June 2018, see https://www.greentechmedia.com/articles/read/breaking-down-the-opposition-to-does-emergency-coal-and-nuclear-bailout-pla#gs.RIAIv=k, accessed 11 July 2018.

339 - Hannah Northey, Peter Behr, "Trump orders DOE to halt coal, nuclear retirements", *E&E News, 1 June 2018, see* https://www.eenews.net/stories/1060083235, accessed 11 July 2018.

340 - *Advanced Energy Economy*, "Broad energy coalition condemns federal action to subsidize failing coal, nuclear plants", 1 June 2018, see https://www.aee.net/articles/broad-energy-coalition-condemns-federal-action-to-subsidize-failing-coal-nuclear-plants, accessed 11 July 2018.

341 - Gilian Giannetti, "The Coal/Nuke Bailout, or DOE's Game of Whack-A-Mole", NRDC, 21 June 2018, see https://www.nrdc.org/experts/gillian-giannetti/coalnuke-bailout-or-does-game-whack-mole, accessed 11 July 2018;

tricity markets." PJM issued a report on 20 June 2018 that confirmed that there were no basis for Federal intervention in the electricity market due to grid insecurity.[342]

As of 1 July, DOE Secretary Perry had yet to announce a decision on whether to enact the Federal Power Act or the Defense Production Act to bail out failing nuclear (and coal) plants.[343]

Table 5 | U.S. State Emission Credits for Uneconomic Nuclear Reactors 2016-2018 as of 1 July 2018

State	Utility	Reactors	Planned Permanent Shutdown Date	Status of Permanent Shutdown Planning	Status of Emissions Credit Legislation	Value	Legal Status
Illinois	Exelon	Clinton-1	June 2017	Cancelled	Illinois Future Energy Jobs Act passed by legislature – June 2016	US$16.50/MWh	Challenged in court
		Quad Cities 1&2	June 2018	Cancelled			
Pennsylvania	Exelon	TMI	September 2019	Planned	No legislation	N/A	N/A
	FirstEnergy	Beaver Valley 1&2	2021	Planned			
New Jersey	PSEG/Exelon	Salem 1&2	Threatened by 2019	Likely to be cancelled	Legislature passed – April 2018 (reactors with operating license through 2030 only)	US$300 million a year	N/A
	PSEG	Hope Creek	Threatened by 2019	Likely to be Cancelled	Eligible		
	Exelon	Oyster Creek	October 2018	Planned	Not eligible (due to 2029 license expiration)		
Connecticut	Dominion	Millstone 2&3	No date	Unclear	Senate Zero Carbon Procurement Act approved by Governor November 2017; maybe not eligible until 2023	US$330 million a year	N/A
New York	Exelon	Fitzpatrick	Threatened	Likely to be cancelled	NYPSC Clean Energy Standard ZEC passed in 2016	US$482 million 2018–2019; US$8 billion 2017–2029	Ongoing challenge
	Entergy	Ginna	Threatened	Unclear			
		Nine Mile Point-1	Threatened	Likely to be cancelled			
Ohio	FirstEnergy	Davis Besse	May 2020	Unclear	Zero Emission Nuclear legislation tabled October 2017, pending hearings	US$180 million per year	N/A
		Perry	May 2021	Unclear			

Sources: Various, compiled by WNISR, 2018

Note

PSEG: Public Service Enterprise Group

On 9 February 2018, the budget bill passed by Congress and signed by President Trump included extension of tax credits for nuclear power, which in effect relate to the only power plant under construction at Plant Vogtle.[344] The extension of the credit, at US$18/MWh, was essential for the continued construction of the two reactors given the certainty of plant Vogtle not meeting the 2020 start-up date. The new budget indefinitely extends the availability of production tax credit for 6 GW of new nuclear capacity. Under the previous budget legislation Vogtle would be required to be operational no later than 31 December 2020, to be entitled to credits,

342 - PJM Interconnection, "Strengthening Reliability: An Analysis of Capacity Performance", Pennsylvania-New Jersey-Maryland Interconnection, 20 June 2018, see http://www.pjm.com/-/media/library/reports-notices/capacity-performance/20180620-capacity-performance-analysis.ashx?la=en, accessed 11 July 2018.

343 - Emma Foehringer Merchant, "Security Experts Implore Sec. Perry to Support Nuclear as DOE Avoids Decision Timeline", *Greentech Media*, 28 June 2018, see https://www.greentechmedia.com/articles/read/security-experts-implore-perry-to-support-nuclear#gs.7Q1zgTA, accessed 11 July 2018.

344 - Darrell Proctor "Nuclear Power, Carbon Capture Winners in New Budget Deal", *POWER*, 9 February 2018, see http://www.powermag.com/nuclear-power-carbon-capture-winners-in-new-budget-deal/?mypower, accessed 9 May 2018.

a deadline it was and is not possible to meet. The extension of tax credit would mean between US$1 and 2 billion in credits would be available over the first eight years of operation, no matter when actual eventual operation begins.[345] The availability of tax credits was considered by the Georgia Public Service Commission (PSC) critical in its December 2017 decision to approve completion of the two AP1000 reactors at Plant Vogtle.

Innovations for Nuclear Rescue Subsidies—An Overview

As reported in *WNISR 2017,* utilities have undertaken major lobbying efforts in recent years to secure financial support at the state level, particularly in the north east and mid-west. Centered around so-called emissions credits, legislation has been adopted or is pending in six states affecting 12 reactors. Table 5 provides an overview and a detailed state-by-state analysis is included at Annex 4.

18 Early Retirement Announcements

Since 2013, reactor utilities in the U.S. have declared 18 reactors for permanent shutdown; with the decision on five of these reactors having subsequently been reversed due to the availability of state Zero Emission Credits (ZEC) legislation (FitzPatrick in New York, Clinton and Quad Cities-1 & -2 in Illinois and Palisades in Michigan); six have been shut down (Crystal River-3 in Florida, San Onofre-2 & -3 in California, Kewaunee in Wisconsin, Vermont Yankee in Vermont and Fort Calhoun in Nebraska); of the remaining reactors declared for permanent closure there seems no prospect that the decisions will be reversed in the cases of Indian Point-2 & -3, Pilgrim in Massachusetts, Oyster Creek in New Jersey, and Diablo Canyon-1 & -2 in California. The number of shutdowns will likely grow further, even with further ZEC legislation adopted.

The future of the two-unit Prairie Island plant in Minnesota remains in doubt. In May 2018, the Minnesota Senate approved legislation that would permit the owner of the two-unit Prairie Island reactors to recover costs of US$1.4 billion for planned retrofits required before 2020. However, the state chamber of commerce is opposed to the bailout and the Governor has threatened to veto it.[346]

Energy economist Mark Cooper commented on the current multiple legislative initiatives of the nuclear industry to secure financial aid to survive the transitioning U.S. electricity market:

> Federal taxpayers fund basic research and development of new nuclear power technologies, underwrite the cost of liability insurance, and socialize the cost of waste management and decommissioning. Local ratepayers subsidize above-market prices for nuclear-generated electricity. And the nuclear industry is clamoring for more subsidies, arguing that markets do not know how to value its product... Providing powerful incentives to pursue uneconomical projects will inevitably saddle ratepayers and the economy with tens of billions of dollars of unnecessary spending in any state that guarantees recovery of costs in advance for new

345 - William Freebairn "US budget bill includes credits for Georgia nuclear plant, small reactors", *S&P Global*, Platts, 9 February 2018, see https://www.platts.com/latest-news/electric-power/washington/us-budget-bill-includes-credits-for-georgia-nuclear-21293499, accessed 9 May 2018.

346 - Mike Hughlett, "Senate passes legislation that would change approval process for Xcel nuclear costs", *Star Tribune*, 14 May 2018, see http://www.startribune.com/senate-passes-legislation-that-would-change-approval-process-for-xcel-nuclear-costs/482597051/, accessed 20 May 2018.

nuclear reactors, or subsidizes aging reactors to keep them online when they no longer can compete.[347]

Table 6 | Early-Retirement Announcements for U.S. Reactors 2009–2025

Reactor	Owner	Decision Date	Shutdown Date (last electricity generation)	Age at Shutdown (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	2021[a]	51	Yes
Indian Point 2&3	Entergy	9 January 2017	No later than 30 April 2020 / 30 April 2021	47 / 44	Under review
Three Mile Island-1	Exelon	30 May 2017	September 2019	45	Yes
Beaver Valley 1&2	First Energy	March 2018	2022	45/34	Yes
Davis Besse-1	First Energy	March 2018	2020	43	Yes
Perry	First Energy	March 2018	2021	35.5	To be submitted October – December 2020

Sources: Various, compiled by WNISR, 2018

Notes:

SCE: Southern California Edison; **SDG&E:** San Diego Gas & Electric; **PG&E:** Pacific Gas & Electric Company; **OPPD:** Omaha Public Power District

a - In September 2017, Entergy announced that "[it reversed] its December 2016 decision to close Palisades on October 1, 2018, but Entergy remains committed to its strategy of exiting the merchant nuclear power business." See Entergy, "Entergy to Continue Operating Palisades Power Plant Until Spring 2022 – Palisades Power Plant", 28 September 2018, see http://www.palisadespower.com/entergy-to-continue-operating-palisades-power-plant-until-spring-2022/, accessed 16 April 2018.

347 - Mark Cooper, "A dozen reasons for the economic failure of nuclear power", Vermont Law School, *Bulletin of Atomic Scientists*, 17 October 2017, see https://thebulletin.org/dozen-reasons-economic-failure-nuclear-power11196, accessed 9 May 2018.

New Reactor Construction

"I believe the future of nuclear energy in the United States is bright... Advanced nuclear energy projects like Vogtle are the kind of important energy infrastructure projects that support a reliable and resilient grid, promote economic growth, and strengthen our energy and national security."

Rick Perry
U.S. Department of Energy (DOE) Secretary
September 2017[348]

The past year has seen the political and financial fallout of the decision to cancel the twin AP1000 reactors at VC Summer in South Carolina escalate, more recently, in September 2017, with the launch of a criminal investigation into plant owner SCANA, in particular on a suspected coverup of the dramatic financial situation of the project. In part as a consequence of securing an extension of federal loan guarantees, the decision was taken to continue with construction of the only other nuclear power plant construction at Plant Vogtle in Georgia.

In addition, Duke Energy announced in August 2017 that it would abandon plans for the construction of the William States Lee nuclear plant in South Carolina.[349] The company plans to seek cost recovery from ratepayers in North and South Carolina for the US$368 million spent on the project so far. The Nuclear Regulatory Commission (NRC) issued a construction license for the Lee plant, in December 2016, which would have been two AP1000 reactors.[350]

On 29 March 2017, Westinghouse Electric Company, a subsidiary of Japanese Toshiba group and the largest historic builder of nuclear power plants in the world, filed for Chapter 11 bankruptcy protection in the U.S. Bankruptcy Court for the Southern District of New York.[351] The insolvency has resulted from a number of factors, most recently, the enormous cost increases and time delays at the four AP1000 reactors under construction at the Alvin W Vogtle plant in Georgia and V.C. Summer in South Carolina. The AP1000 reactor projects are managed by Chicago Bridge and Iron (CB&I) Stone and Webster, a subsidiary of Westinghouse Electric Company LLC, which was purchased by Toshiba in 2006. The cost overruns on these projects are the principal cause of US$6.2 billion in losses declared by Westinghouse parent company Toshiba.

On 9 February 2012, for the first time in nearly three and a half decades, the NRC granted a Construction and Operating License (COL) for the Vogtle-3 and -4 units. On 30 March 2012, South Carolina Electric & Gas (SCG&E) received the second COL for units 2 and 3 at its Summer site. In an unprecedented move, Gregory B. Jaczko, the then Chairman of the NRC,

348 - 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 5 May 2018.

349 - Robert Trigaux, "Trigaux: Abandoning another nuclear project, Duke Energy mimics its failed Levy plant", *Tampa Bay Times*, 25 August 2017, see http://www.tampabay.com/news/business/energy/trigaux-abandoning-another-nuclear-project-duke-energy-mimics-its-failed/2335162, accessed 20 May 2018.

350 - U.S.NRC, "NRC Issues New Reactor Licenses to Duke Energy for William States Lee III Site in South Carolina", 21 December 2016, see https://www.nrc.gov/reading-rm/doc-collections/news/2016/16-075.pdf, accessed 20 May 2018.

351 - U.S. Bankruptcy Court, "Case 1:17-bk-10778—Westinghouse International Technology LLC—Bankruptcy Petition #: 17-10778-mew", Southern District of New York (Manhattan), filed 29 March 2017, see https://www.inforuptcy.com/filings/nysbke_273415-1-17-bk-10778-westinghouse-international-technology-llc-docket_text, accessed 27 May 2017.

voted against the opinion of the four other Commissioners, stating that the decision was being taken "as if Fukushima never happened".[352] Jaczko subsequently resigned from his NRC position.

Construction of Vogtle-3 officially began in March 2013,[353] with unit 4 following in November 2013.[354] The original cost estimate for the two AP1000 reactors at Plant Vogtle was US$14 billion. By June 2017, one estimate for project completion put the cost at US$29 billion.[355] The construction of the Vogtle and V.C. Summer reactors were already in severe difficulty long before the declaration of bankruptcy by Westinghouse. For example, as disclosed in early 2018 during the discovery process of ongoing legal proceedings following the cancellation of the VC Summer project, in February 2014, the utilities wrote to Westinghouse that Shaw—a company picked by the contractors to produce the AP1000—"proved to be neither equipped nor qualified to produce the modules."[356] (For more background on the AP1000 design problems see WNISR2016 and 2017).

Vogtle AP1000 Project[357]

"I Wouldn't Bet My House"
Stan Wise
outgoing chairman of the Georgia PSC on Plant Vogtle schedule
after voting to continue the project
21 February 2018[358]

As construction continued at the Vogtle site during summer 2017, Southern Company, the parent company of Georgia Power, stated 4 August 2017 that it planned to file its recommendation to the Georgia Public Service Commission (PSC) on whether to proceed or not with Plant Vogtle construction by the end of the month.[359] In the following months the controversy around the much delayed and multi-billion dollar cost overruns escalated, centered around the decision to be made by Georgia's PSC, whether or not to approve the financial package that would see further higher costs for the state's ratepayers.

On 31 August 2017, the Southern Company (parent company of majority Vogtle plant owner, Georgia Power) filed its recommendation with the Georgia PSC to continue construction of

352 - *MSNBC*, "U.S. licenses first nuclear reactors since 1978", 9 February 2012. 296 - WNISR, "Construction Start at Vogtle Reactor in the US", 16 March 2013.

353 - WNISR, "Construction Start at Vogtle Reactor in the US," 16 March 2013, see https://www.worldnuclearreport.org/Construction-Start-at-Vogtle.html, accessed 27 May 2017.

354 - WNISR, "Construction Start on US Vogtle Unit 4", 25 November 2013, see https://www.worldnuclearreport.org/Construction-Start-on-US-Vogtle.html, accessed 22 May 2018.

355 - Darrell Proctor, "Cost Overruns at Vogtle Expected to Soar", *POWER Magazine*, 19 June 2017, see http://www.powermag.com/cost-overruns-at-vogtle-expected-to-soar/, accessed 5 August 2017.

356 - Avery G. Wilks, Sammy Fretwell "Thousands of records tell story of failed nuclear plant, could lead to SCE&G refunds", *The State*, 19 March 2018, see https://www.greenvilleonline.com/story/news/2018/03/19/thousands-records-tell-story-failed-nuclear-plant-could-lead-sce-g-refunds-read-more-here-http-t/437669002/, accessed 24 May 2018.

357 - All documents related to the construction monitoring are available on the website of the Public Service Commission, see http://www.psc.state.ga.us/factsv2/Docket.aspx?docketNumber=29849.

358 - Denis O'Hayer, "Outgoing PSC Chairman: 'I Wouldn't Bet My House' On Plant Vogtle Schedule", *WABE*, 21 February 2018, see https://www.wabe.org/outgoing-psc-chairman-wouldnt-bet-house-plant-vogtle-schedule/, accessed 11 July 2018.

359 - Georgia Power, "Georgia Power to finalize Vogtle assessments by end of August", 4 August 2017, see https://southerncompany.mediaroom.com/2017-08-04-Georgia-Power-to-finalize-Vogtle-assessments-by-end-of-August, accessed 21 May 2017.

Vogtle, which was supported by the other owners of the plant, Oglethorpe Power, MEAG Power and Dalton Utilities.[360] In addition to continuation of the project, Georgia Power reported that it had also reviewed the options of cancellation of unit 4, as well as cancellation of both units.

The recommendation was based on the results of a comprehensive schedule, cost-to-complete and cancellation assessment, according to Southern. The President of Georgia power stated that, "Completing the Vogtle 3 & 4 expansion will enable us to continue delivering clean, safe, affordable and reliable energy to millions of Georgians, both today and in the future".[361] The decision included the availability of financial support and on the assumption that monies would be forthcoming, specifically future payments from Toshiba, availability of production tax credits and extension of DOE loan guarantees. The specific request to the PSC was that the, "Commission approves the new cost and schedule forecast and finds that it is a reasonable basis for going forward; and that if the Commission disapproves all or part of the proposed cost and schedule revisions, the Company may cancel Units 3 and 4 and recover its actual investment in the partially completed Facility".[362] Georgia Power also requested that the PSC not consider the current cost recovery 'a cap' indicating that future cost rises would lead to further ratepayer increased costs. For perhaps other than legal reasons, and given the remaining uncertainties in the viability of the project, the utility also noted that "as conditions change and assumptions are either proven or disproven, the owners and the Commission may reconsider the decision to go forward."

Southern gave figures of US$19 billion for the total estimated capital cost of the project, of which its share would be US$8.8 billion, US$4.3 billion of which it had invested in capital costs as of June 2017 with additional costs of US$4.5 billion through to completion.[363] The credibility of these cost estimates, as in the past years, were to be a central focus of those opposed to the project completion, and even PSC own staff during the remainder of the PSC review process. The original cost estimate for the project was US$11 billion. As a result of the bankruptcy of Westinghouse, Georgia Power also announced on 31 August 2017 that it had contracted Bechtel to manage daily construction efforts at Vogtle, Paul Bowers, chairman, president and CEO of Georgia Power claiming "we can do a better job than Westinghouse alone as we move forward to complete the project".[364]

Southern gave fuel-loading times as November 2021 for Unit 3 and November 2022 for Unit 4, which compares with an original startup date of 2016. However, the operational dates from Southern are at variance with the assessment made by the Georgia PSC in its December 2016 quarterly progress report, which indicated a credible completion date of 2023. Obtained by

360 - Southern Company, "Southern Company subsidiary Georgia Power files recommendation to complete construction of Vogtle nuclear expansion", 31 August 2017, see https://www.southerncompany.com/newsroom/2017/aug-2017/georgia-power-vogtle-recommendation.html, accessed 22 May 2018.

361 - Ibidem.

362 - Georgia Public Service Commission, "Georgia Power Company's Seventeenth Semi-Annual Construction Monitoring Report, Request For Approval Of The Expenditures Made Between January 1, 2017 And June 30, 2017, And Request For Approval Of The Revised Project Cost Estimates And Construction Schedule Pursuant To O.C.G.A. § 46-3a-7(B)", Docket No. 29849, 31 August 2017, see http://www.psc.state.ga.us/factsv2/Document.aspx?documentNumber=169459, accessed 12 August 2018.

363 - Georgie Public Service Commission, "Vogtle 3&4 Estimate to Complete (ETC) Report", ETC Report, submitted to the Georgia Public Services Commission, 31 August 2017, see http://www.psc.state.ga.us/factsv2/Document.aspx?documentNumber=169459, accessed 22 May 2018.

364 - Southern Company, "Southern Company subsidiary Georgia Power files recommendation to complete construction of Vogtle nuclear expansion", 31 August 2018, see https://www.southerncompany.com/newsroom/2017/aug-2017/georgia-power-vogtle-recommendation.html, accessed 9 August 2018.

EnergyWire[365]—one public version, the other classified as 'Highly Confidential Trade Secret EPC Information'—the report cast major doubts on the company estimated completion dates of the Vogtle reactors, with future long-term activities identified by "staff as high risk for delay." Although both versions of the report were heavily redacted, it confirmed that "there have been continued delays from the November 2016 Integrated Project Schedule ("IPS") to the December 2016 IPS for many Unit 3 and 4 activities" and "that all of the paths to Unit 3 completion are under schedule stress and will likely incur additional delays."[366] The 2023 date itself was highly speculative, and was on the basis of maintaining the 2016 nine percent annual construction completion rate, with no further delays, which given the track record of the project must be in serious doubt.

Georgia Power's submission to the PSC gave estimates for Vogtle's cancellation of between US$730 million and US$760 million (for all partners), of which Georgia Power's share totals approximately US$330 million to US$350 million exclusive of estimated credits from the salvage and sale of assets.[367] Cancellation of only Vogtle-4 was estimated at US$420 million to US$490 million, (for all partners) of which Georgia Power's share totals approximately US$190 million to US$225 million, exclusive of asset sales. After US$4.8 billions of costs engaged by Georgia Power as of June 2017, the company reported that asset sales and salvage of the project could net a fraction of those costs of approximately US$15 million to US$50 million, of which Georgia Power's share would be US$5 million to US$20 million.

Financial agencies still considered the risk of cancellation, noting that it was dependent on financial mechanisms being secured, with Fitch reporting in August 2017: "A decision to abandon Vogtle-3 and -4 cannot be completely ruled out and could be driven by the non-payment of Toshiba guarantee payments that start in October or an adverse regulatory order".[368]

A key difference in the decision to proceed with Plant Vogtle, in contrast to VC Summer, were the different commercial terms for the projects, including original engineering, procurement and construction contract and the guarantees provided by Westinghouse parent company Toshiba.[369] The Vogtle owners had an agreement with Toshiba to receive US$3.68 billion to resolve its guarantees of the contract, compared to US$2.17 billion for the VC Summer plant. As noted, securing the monthly payments (which were originally due to run through 2021) from Toshiba amounting to a total of US$3.68 billion was also critical to the decision to continue with Vogtle.[370] The uncertainty around Toshiba's payments were resolved when payments began in October 2017, and the full balance of US$3.68 billion was paid to Southern and partners by December 2017.[371]

365 - 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 2017.

366 - Georgia PSC, "Vogtle 3 and 4 Nuclear Project Monthly Report—Public Disclosure", December 2016, see https://www.eenews.net/assets/2017/02/08/document_ew_02.pdf, accessed 28 May 2017.

367 - Opcit. Georgia Power 31 August 2017.

368 - Ibidem.

369 - *NW*, "Decision looms on completing Georgia Power's Vogtle expansion", 31 August 2017.

370 - *NW, "Vogtle future may depend on Toshiba chip business sale, analysts say", 7 September 2017.*

371 - Georgia Power, "Toshiba fulfills $3.68 billion parent guarantee obligation for Vogtle nuclear expansion", *PRWire*, 14 December 2017, see https://www.prnewswire.com/news-releases/toshiba-fulfills-368-billion-parent-guarantee-obligation-for-vogtle-nuclear-expansion-300571464.html, accessed 22 May 2018.

Project management will be taken over by Southern Nuclear Operating Co., with construction and engineering company Bechtel performing day-to-day work, Georgia Power said in its PSC filing.

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 assurance of the U.S. Government.

DOE loan guarantees permit 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 reduces overall financing costs. In justification for the loan guarantee to Vogtle, the Obama administration stated in 2010 that "the Vogtle project represents an important advance in nuclear technology, other innovative nuclear projects may be unable to obtain full commercial financing due to the perceived risks associated with technology that has never been deployed at commercial scale in the U.S. The loan guarantees from this draft solicitation would support advanced nuclear energy technologies that will catalyze the deployment of future projects that replicate or extend a technological innovation."[372]

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 United States in the coming decades. Oglethorpe, which has a 30 percent stake in Vogtle, confirmed August 2017 that it had submitted a request to the 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 reported 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 Oglethorpe Power Corporation (OPC), and US$415 million to MEAG.[373] A decision on terminating the Vogtle project would raise the prospect of repayment of the US$8.3 billion previous loan to Southern.[374]

Costs to Customers and the Position of the Public Services Commissions

The Georgia Public Service Commission (PSC) has backed the Plant Vogtle project from the start, including awarding generous Combined Works In Progress (CWIP), where all construc-

372 - Peter W. Davidson, "Fostering the Next Generation of Nuclear Energy Technology", Loan Programs Office, U.S.DOE, 29 September 2014, see https://energy.gov/lpo/articles/fostering-next-generation-nuclear-energy-technology, accessed 28 May 2017.

373 - 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 22 May 2018.

374 - 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 22 May 2018.

tion 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 legislations, 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 going up by an average of US$3.73 per month. Georgia Power estimates that this monthly charge will escalate so that by 2018, a Georgia Power residential customer using 1,000 kWh per month will see their bill go up by US$10 per month due to Vogtle-3 and -4.

In reality, as a result of increased costs of the project and approval by the PSC, ratepayers had already paid US$2 billion to Georgia power as of November 2017.[375]

Utilities like CWIP because it gives them an interest-free loan from their customers rather than market-rate debt and equity financing. However, CWIP increases their risk, because price elasticity and political dissatisfaction will both have longer to work before the plant is ultimately finished (if it is) and put in the rate-base. Georgia's special law is considered by the builders to relieve them of all cost-overrun or imprudent-investment risk, but even if it did—which will be ultimately up to the courts—the state regulator has many other tangible ways to express its displeasure, if it feels a regulated utility has been unwise, imprudent, or deceitful.

Given the delays in the project and multiple-billion cost-overruns, any future costs sought by the owners of Vogtle to be covered under CWIP would need PSC approval. Already challenged on the projects viability since before construction of the plants, public criticism of the failure of the PSCs in Georgia to act prudently had only increased in recent years and has escalated since the bankruptcy filing of Westinghouse.

Georgia Public Services Commission

Leading up to the decisive Georgia Public Services Commission (PSC) public hearing in December 2017, indications were that at least one member of the PSC remained supportive of the Vogtle project was a commentary in mid-August from the PSC Vice-Chairman. He stated that Georgia was "pressing ahead" with the Vogtle expansion. "Today, finishing the Vogtle plant's two new Westinghouse AP1000 reactors is the right call—for their owners, including Southern Co., as well as for Georgia and the U.S."[376]

The key decision of the PSC was, whether to allow Georgia Power to recover all costs under CWIP for completing the Vogtle units from ratepayers. Georgia Power said in the filing that should the PSC not approve such cost recovery, the four co-owners would seek to abandon the project.

375 - Southern Environmental Law Center, "Groups Intervene in Vogtle Cost Proceedings", 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 22 May 2018.

376 - Dave Flessner, "Georgia regulators question economics of completing nuclear plant", *Times Free Press*, 7 December 2017, see http://www.timesfreepress.com/news/business/aroundregion/story/2017/dec/07/georgiregulators-questieconomics-completing-n/458694/, accessed 23 May 2018.

In advance of the PSC making a decision on Vogtle, its own Public Interest Advocacy Staff in a detailed submission on 1 December 2017, recommended that multiple costs Southern were seeking to recover from state ratepayers were unreasonable, and made recommendations to the PSC in advance of their decision on whether to approve financing for the project later in December. The submission stated:

Given all of the concerns regarding Company and Contractor performance to date, including cost overruns and the inability to meet previously submitted schedules for commercial operation, Staff believes it is not appropriate to allocate all of the Company's forecast cost increase to ratepayers.[377]

They noted that electricity from the new reactors would cost customers US$1.6 billion more than other energy sources and that construction should be ended unless Georgia Power covers nearly another US$4 billion in estimated costs for the project.[378] The PSC Staff advised the PSC that if their recommendations for reducing costs, and not to exceed US$9 billion, to ratepayers were incorporated into the PSC agreement with Southern and partners, then the project should proceed; if not, then they recommended cancellation of the project.

> *"It would be unreasonable for the company to recover any cost above US$9.0 billion from the ratepayers..."*

Four days of public hearings on Vogtle opened on 11 December 2017 that pitched Southern and partners against a broad and expanding coalition of environmentalists, public interest groups, clean energy advocates, and ratepayers, along with their lawyers and expert witnesses opposed to the PSC granting further subsidies to the Vogtle project. At the opening of the hearings, it was confirmed that the decision of the PSC would be advanced from February 2018 to 21 December 2017.[379] PSC Staff, financial analysts, and expert witnesses all testified that Georgia ratepayers should not be saddled with all the cost overruns because of Georgia Power's poor management. Georgia Power was seeking PSC approval for full recovery of its costs of US$12.2 billion to complete the project. "It would be unreasonable for the company to recover any cost above US$9.0 billion from the ratepayers, and cost above US$9 billion should be absorbed by the Company," testified the Director of Utility Finance for the PSC Staff.[380]

Under cross examination from Georgia Watch, a public interest group, PSC staff confirmed that "the nominal life cycle capital cost revenue requirement collected from ratepayers would increase from US$23 billion to US$37 billion... (and that) if the Commission adopts the Company's recommendations as filed, the Company profits will increase by US$5.2 billion dollars and ratepayers will pay an additional US$14 billion dollars."[381]

377 - Georgia Public Services Commission, "Direct Testimony and Exhibits Tom Newsome PE, CFA", 1 December 2017, see https://www.eenews.net/assets/2017/12/04/document_ew_02.pdf, accessed 12 August 2018.

378 - Ibidem.

379 - Daniel Tait, "Stan Wise may be gift-wrapping an early Christmas present for Georgia Power at customers' expense", Energy and Policy Institute, 12 December 2017, see http://www.energyandpolicy.org/stan-wise-georgia-power-speed-up-timeline-for-vote-on-vogtle/, accessed 23 May 2018.

380 - Gloria Tatum, "Ratepayers, Experts Urge Psc To Cancel Vogtle Nuclear Reactors 3 And 4 (update 1)", *Atlanta Progressive News*, published by Georgia watch, 19 December 2017, see http://www.georgiawatch.org/ratepayers-experts-urge-psc-to-cancel-vogtle-nuclear-reactors-3-and-4-update-1/, accessed 23 May 2018.

381 - Georgia Watch, «Ratepayers, Experts Urge PSC to Cancel Vogtle Nuclear Reactors 3 and 4 (Update 1), see http://www.georgiawatch.org/ratepayers-experts-urge-psc-to-cancel-vogtle-nuclear-reactors-3-and-4-update-1/, accessed 18 August 2018.

The PSC Director of utility finance warned of the possibility of continued financial losses with Vogtle construction, and that more delays beyond those projected by Georgia Power and its project partners "could make the expansion an even worse deal, by as much as US$4.9 billion, noting more delays would have, 'a significant adverse impact' on costs."[382]

On 21 December 2017, the PSC Commissioners unanimously approved continuation of construction for the two AP1000 Vogtle reactors.[383] The decision had the attached condition that will reduce Georgia Power's revenue requirements by US$1.7 billion from ratepayers over the construction and operation of the plant. The Commissioners made their approval contingent on the project securing federal tax credits. However, the decision did not reflect the recommendations of the PSC's Public Interest Advisory Staff to not exceed US$9 billion, instead agreeing capital construction costs of US$7.3 billion and financing costs of US$3.4 billion,[384] a figure that in total is 75 percent above the original PSC certified cost.

PSC Chair Stan Wise, despite stating in May 2017 that, "if I'd known any of this a decade ago we would have gone a different way," voted in favor of the Vogtle project along with his four other commissioners. Wise came in for particular criticism for his role and vote from opponents of the project. In February 2018, Wise stated: "I wouldn't bet my house on plant Vogtle schedule".[385] He retired from the PSC the same month.

The PSC decision that found the project 'cost effective' comes despite the enormous cost increases to Georgia ratepayers. The original project cost approved by the PSC was US$6.1 billion in 2009, which corresponds to a cost of US$2,350/kW; whereas as the latest cost estimates of US$23 billion would lead to a cost of US$10,000/kW. The Massachusetts Institute of Technology (MIT) in its 2011-assessment of the prospects for new nuclear power had based its report on US$4000/kW,[386] while critics of the project had predicted over the last decade that costs would be as high as now confirmed.[387]

While Georgia Power welcomed the decision of the PSC stated that the project will be completed,[388] opponents were scathing. While the commissioner condition will see the profit for Georgia Power reduced by US$700 million it is a fraction of the billions of dollars Georgia Power stands to receive over the lifetime of the project. As the attorney for the Southern Environmental Law Center, one of the intervenors in the PSC proceedings reacted: "Most

382 - Darrell Proctor, "Georgia PSC Will Decide Vogtle's Fate on December 21", *POWER Magazine*, 11 December 2017, see http://www.powermag.com/georgia-psc-will-decide-vogtles-fate-on-december-21/, accessed 23 May 2018.

383 - Kevin Randolph, "Georgia PSC approves Georgia Power's recommendation to move forward with Vogtle nuclear expansion", *Daily Energy Insider*, 21 December 2017, see https://dailyenergyinsider.com/featured/9734-georgia-psc-approves-georgia-powers-recommendation-move-forward-vogtle-nuclear-expansion/, accessed 23 May 2018.

384 - Ibidem.

385 - Denis O'Hayer, "Outgoing PSC Chairman: 'I Wouldn't Bet My House' On Plant Vogtle Schedule", *WABE*, 21 February 2018, see https://www.wabe.org/outgoing-psc-chairman-wouldnt-bet-house-plant-vogtle-schedule/, accessed 23 May 2018.

386 - MIT, "The Future of the Nuclear Fuel Cycle—An Interdisciplinary MIT Study", Massachusetts Institute of Technology, 2011, see https://energy.mit.edu/wp-content/uploads/2011/04/MITEI-The-Future-of-the-Nuclear-Fuel-Cycle.pdf, accessed 23 May 2018.

387 - For example, see Michael Marriotte,"MIT Nuke Study Uses Unsupportable Reactor Cost Estimates", Nuclear Information and Resource Service, 16 September 2010, see https://www.commondreams.org/newswire/2010/09/16/mit-nuke-study-uses-unsupportable-reactor-cost-estimates, accessed 23 May 2018; and Maryland PIRG "The High Cost of Nuclear Power—Why America Should Choose a Clean Energy Future Over New Nuclear Reactors", March 2009, see https://www.nirs.org/wp-content/uploads/nukerelapse/calvert/highcostnpower_mdpirg.pdf, accessed 23 May 2018.

388 - Georgia Power, "Georgia Power will move forward with Vogtle 3 and 4 project", 21 December 2017, see https://www.georgiapower.com/company/plant-vogtle/vogtle-news/2017-articles/georgia-power-will-move-forward-with-vogtle-3-and-4-project.html, accessed 23 May 2018.

people have to pay for their mistakes, but Georgia Power is still profiting from theirs...There's something wrong with a system that rewards this kind of failure."[389]

> *"ongoing construction cost risk will persist at Vogtle Units 3&4"*

Following the decision to proceed with construction, Fitch's credit rating note in January 2018 stated: "Ongoing construction cost risk will persist at Vogtle Units 3&4 through the revised completion dates in 2021 and 2022, and that Georgia Power Company and MEAG Power competitiveness could become strained, and that Oglethorpe's total debt is expected to grow to approximately US$11 billion by fiscal 2022."[390]

In February 2018, U.S. Congress approved extending the timeframe for electricity production tax credits (PTCs), and established under the 2005 Energy Policy Act, which effectively reduces the risk to Southern and partners for continuing construction of Vogtle and other new nuclear plants.[391] As a result of the delays in plant construction, Vogtle was guaranteed to miss the current timeframe for existing PTCs where the reactors to be eligible were required to be operating before December 2020. The new legislation, signed by President Trump as part of the overall budget, Vogtle itself will qualify for an income credit of US$c1.8/kWh of electricity produced and sold. The approval of PTCs met one of the conditions required by the Georgia PSC.

Georgia Power reported in its Eighteenth Semi-annual Vogtle Construction Monitoring Report, that the total project was 65 percent complete, while actual construction was at 48.5 percent.[392] This compares with construction being 36 percent complete as of September 2016.[393] The implication of this state of construction is that the Vogtle project is not on track to meet its stated fueling dates of 2021 and 2022. The December 2016 quarterly progress report of the PSC warned that a more reasonable completion date was 2023, but this was on the basis of maintaining an annual construction rate of nine percent.[394] The latest disclosures from Georgia Power confirm only 12 percent of construction was completed over a period of 16-17 months to February 2018. The prospects for Georgia Power and partners meeting their stated completion dates lack credibility, and with further financial implications for Georgia ratepayers.

On 13 February 2018, a coalition of groups filed to court a complaint challenging the PSC decision, declaring that it was unlawful, violating the PSC's own guidelines and Georgia state

389 - Southern Environmental Law Center, "Public Service Commission Stiffs Georgia Power Customers, Greenlights Plant Vogtle Cost Increases", 21 December 2017, see https://www.southernenvironment.org/news-and-press/press-releases/public-service-commission-stiffs-georgia-power-customers-greenlights-plant, accessed 23 May 2018.

390 - Fitch, "Fitch Rates Oglethorpe Power Corp., Ga 'A-'& Removes Negative Watch; Outlook Stable", 19 January 2018, see http://opc.com/wp-content/uploads/2018/02/Fitch-Ratings-Report-on-OPC-1-19-2018.pdf, accessed 23 May 2018.

391 - *NEI*, "Congress Passes Nuclear Tax Credit in Big Boost for New Construction", 9 February 2018, see https://www.nei.org/news/2018/congress-passes-nuclear-production-tax-credit, accessed 23 May 2018.

392 - Georgia Power, "Eighteenth Semi-annual Vogtle Construction Monitoring Report", Docket No. 29849, February 2018, see http://www.psc.state.ga.us/factsv2/Document.aspx?documentNumber=171384, accessed 23 May 2018.

393 - 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 2017.

394 - Ibidem.

law.[395] The coalition contends that new investments in solar power and energy efficiency would be less risky, more affordable, and more than up to the job of powering Georgia's economy.

Southern Company in May 2018 reported a forty percent increase in its first quarter earnings which were US$958 million compared with US$638 million for the same period in January 2017.[396] Under the financing terms agreed with the PSC, as well as at Federal level, the longer the Vogtle plant takes to construct the higher the costs, which translates into higher earnings for Georgia Power...

Termination of V.C. Summer Project - The Fallout

While Santee Cooper and SCANA Corporation (the parent company of South Carolina Electric & Gas or SCG&E) finally a decision, on 31 July 2017, to terminate construction of the V. C. Summer project (see Figure 28), the past year has seen major political, financial and legal fallout for the companies. Criminal proceedings against the companies were launched in September 2017. By year end, as Santee Cooper sought to extricate itself from costs of termination, SCANA was accusing its partner of "breach and default" in its cancellation of the project, with both each accusing the other of serious harm.[397] Santee Cooper is the public owned utility in South Carolina. Both corporations attributed their decisions primarily to the expected cost and time overruns, if the project had been completed. Santee Cooper said that its analysis showed "the project would not be finished until 2024, four years after the most recent completion date provided by Westinghouse and would end up costing Santee Cooper customers a total of US$11.4 billion".[398] Likewise SCANA's evaluation of "the project costs and schedules" led it to conclude "that completion of both Units would be prohibitively expensive".

As a result of the Base Load Recovery Act (BLRA), South Carolina saw their SCG&E electricity rates increase as the VC Summer project continued to fail while escalating in costs; specifically a US$174 million increase in 2011, US$278 million in 2012, US$699 million in 2015 and US$831 million in 2016. As ratepayer anger in South Carolina surged in the aftermath of the VC Summer cancellation and its financial implications, on 11 August 2017 Santee Cooper withdrew its request to the Public Service Commission (PSC) for further rate recovery, which would have netted it US$2 billion.[399]

395 - 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 23 May 2018.

396 - United States Securities And Exchange Commission, "Quarterly Report Pursuant To Section 13 Or 15(D)Of The Securities Exchange Act Of 1934, For the quarterly period ended March 31, 2018", 2 May 2018, see https://investor.southerncompany.com/information-for-investors/investor-information/sec-filings/default.aspx, accessed 23 May 2018; and Southern Company, "Southern Company reports first-quarter 2018 earnings", 2 May 2018, see https://www.southerncompany.com/newsroom/2018/may-2018/soco-2018-q1-earnings.html, accessed 23 May 2018.

397 - Thad Moore, "Georgia is likely to continue its nuclear project while S.C. decides if its reactors are done for good", *Post and Courier*, 20 December 2017, see https://www.postandcourier.com/business/georgia-is-likely-to-continue-its-nuclear-project-while-s/article_ec8f3ae0-e5c1-11e7-a447-9f490612b93f.html, accessed 24 May 2018.

398 - WNISR, "Utilities Abandon V. C. Summer AP1000 Reactor Construction Following Westinghouse Bankruptcy", 2 August 2017, see https://www.worldnuclearreport.org/Utilities-Abandon-V-C-Summer-AP1000-Reactor-Construction-Following-Westinghouse.html, accessed 5 August 2017.

399 - Santee Cooper, "Santee Cooper Board Cancels Rate Adjustment Process", 11 August 2017, see http://www.pressreleasepoint.com/santee-cooper-board-cancels-rate-adjustment-process, accessed 15 August 2018.

Figure 28 | Abandoned V.C. Summer Construction Site in South Carolina

Courtesy of High Flyer © 2018

The multiple legal challenges to South Carolina Electric & Gas (SCE&G), (12 by 1 July 2018) included in June and August 2017 legal filings (and subsequent) by Friends of the Earth and Sierra Club to the PSC sought rate recovery costs of US$5 billion from the nuclear companies and for discovery and the need for hearings on the companies' efforts to recover costs for the abandoned project.[400] The groups are contesting that ratepayers have seen their electricity rates escalate due to the failed project, and rather than the PSC approving SCE&G request to recover further costs for project abandonment, ratepayers should be reimbursed for costs already they have covered. As Tom Clements of Savannah River Watch and Friends of the Earth (FOE) noted, "currently about 18% of the average SCE&G bill, or about US$27 dollars per month, are a result of the nine annual rate hikes under the BLRA to pay for SCE&G's financing costs of the nuclear project. This forced payment before the plant was on line has resulted in about US$1.7 billion having already been collected in advance from captive ratepayers by

400 - Multiple filings have been made subsequently, including in April 2018 a second discovery request, for all filings see South Carolina Public Services Commission, Docket Management System, available at https://dms.psc.sc.gov/Web/dockets/Detail/116365. See Public Service Commission Of South Carolina, "Friends of the Earth and Sierra Club, Complainant/Petitioner v. South Carolina Electric & Gas Company, Defendant/Respondent—Staff Presents for Commission Consideration Complainants' Request for Oral Argument and Defendant's Request for Suspension of Discovery and Prefile Testimony Deadlines", Docket No. 2017-207-E, 2 August 2017, see https://dms.psc.sc.gov/Attachments/Matter/feb39614-8dc9-4573-8aa1-562aaa665d5a, accessed 24 May 2018.

SCE&G."[401] Clements along with FOE in 2009 had filed legal challenges to the original PSC decisions to approve the construction of the VC Summer reactors, including on the certainty of major cost over runs.[402] In 20 December 2017, the PSC upheld the Friends of the Earth and Sierra Club case, dismissing SCE&G motion to deny, the result of which could see a rate reduction of 18 percent, and payback to ratepayers.[403]

In September 2017, a confidential report prepared by Bechtel in February 2016 for the owners of VC Summer highlighted that problems with labor productivity, project oversight and construction planning were known about 18 months before the project was canceled by the power companies involved.[404] The report was ordered to be released by the South Carolina Governor after the company had refused to make it public on the grounds that it would damage the company in legal proceedings. The report's technical details also raise additional challenging questions about the Vogtle project as it proceeds with construction. Specifically, Bechtel reported that there is "an industry wide issue" involving the fabrication of hollow structural steel tubing, which has wall thicknesses less than what is required in standards developed by the ASTM organization, and that Westinghouse is working on a plan to allow use of the steel tubing at Summer and at Georgia Power's similar Vogtle station expansion.[405]

The release of the report, which had been strongly resisted by the nuclear companies prompted lawmakers in South Carolina to demand that the state's PSC block efforts by SCE&G from recovering billions of dollars in costs. "If they had data that said this project was in trouble and they chose to ignore it and dumped billions of dollars more ratepayer money into it, all the while earning a profit, I think the political atonement for that is going to be enormous," said a state Republican on a South Carolina House committee investigating the project failure.[406] Ratepayers in the state had already paid US$1.7 billion under the state CWIP. SCE&G had filed, then withdrew, a request to the PSC in August 2017 for a further US$2.2 billion to close the project. Under a 2007 state law, SCE&G needs the Public Service Commission's approval to abandon the project and recover the US$4.9 billion it has spent building the plant. The issue centers on whether the PSC would rule that the decision to terminate VC Summer was 'prudent'. If so, then the companies would be in a position to recover costs for ratepayers. However, opponents of the VC Summer warned that the Bechtel report "was fatal to SCE&G in forcing ratepayers to pay abandonment costs." The report also may allow ratepayers to recover some of the US$1.7 billion already paid.

401 - For detailed timeline breakdown of the failure of the South Carolina PSC to challenge SCE&E costs over the past decade see Tom Clements, "Public Interest Testimony Presented in absentia from the Witness List of the Senate's V. C. Summer Nuclear Project Review Committee and House Utility Ratepayer Protection Committee", Friends of the Earth, 22 August 2017, see https://1bps6437gg8c169i0y1drtgz-wpengine.netdna-ssl.com/wp-content/uploads/2017/08/testimony-in-absentia-August-22-2017.pdf, accessed 24 May 2018.

402 - Friends of the Earth "S.C. Reactor Decision Appealed to State Supreme Court", 22 May 2009, see https://foe.org/news/2009-05-sc-reactor-decision-appealed-to-state-supreme-court/, accessed 24 May 2018.

403 - Sammy Fretwell, "Ratepayers win victory in fight to recover money from failed SCE&G nuclear project", *The State*, 20 December 2017, see http://www.thestate.com/news/local/article190819319.html, accessed 24 May 2018.

404 - Santee Cooper, "VC Summer Nuclear Generating Stations Units 2&3 Project Assessment, February 2016", Bechtel; and WNA, "US governor releases report on VC Summer flaws", 6 September 2017, see http://www.world-nuclear-news.org/C-US-governor-releases-report-on-VC-Summer-flaws-06091701.html, accessed 24 May 2018.

405 - *NW*, "Internal 2016 report on Summer expansion found oversight, construction issues", 17 September 2017.

406 - Avery Wilks, Sammy Fretwell, "Long-secret report could save SCE&G's customers billions", *The State*, SC Small Business Chamber of Commerce, 6 September 2017, see https://scsbc.org/long-secret-report-save-scegs-customers-billions/, accessed 11 July 2018.

In late September 2017, the South Carolina House Speaker Jay Lucas, along other representatives requested the South Carolina Law Enforcement Division (SLED) to initiate an investigation for potential criminality on the part of SCANA and its principal subsidiary, SCE&G, stating: "If, as we suspect, criminal activity exists at the root of the V.C. Summer disaster, it is imperative that it be discovered as quickly as possible and that those responsible are held accountable for their actions."[407]

> *"the defendants knew or should have known that the project was not economically viable"*

Amongst multiple lawsuits filed during 2017 were two class action lawsuits by ratepayers seeking compensation for 70,000 customers in South Carolina as well as shareholders of SCE&G and SCANA, noting that, "the defendants knew or should have known that the project was not economically viable and was not progressing at a proper pace much earlier," according to the lawsuit. The ratepayers' lawsuit charged the companies with "fraud and negligence in the years preceding the decision to abandon construction of the company's nuclear power plants".[408]

On 22 September 2017, the South Carolina Attorney requested SLED to launch a criminal investigation related to the VC Summer project. While on 26 September 2017, the Office of Regulatory Staff (ORS), which represents ratepayers and industry in the state before the Public Service Commission, issued an opinion to the PSC that portions of the Base Load Recovery Act (BLRA), by which SCG&E recovers costs from ratepayers for VC Summer are constitutionally suspect, and which directed the company to immediately suspend collecting the revised rates. These amounted to US$445 million in 2017, 18 percent of ratepayers' annual bill. The ORS requests that if the BLRA is later found to be unconstitutional by a court or if the General Assembly amends or revokes the BLRA, that the SCPSC issues an order requiring SCE&G to make refunds to customers for prior revised rates collections. SCE&G responded that the request is illegal, and the PSC should uphold the law as written.[409] The PSC deferred action at that time until hearings on the ORS request, which ordered at PSC meeting in December 2017.[410]

In October 2017, it was confirmed that the U.S. Securities and Exchange Commission had issued a subpoena against SCG&G related to an investigation of the canceled Summer nuclear plant construction project.

407 - WLTX, "House Asks SLED to Investigate SCE&G Over VC Summer Failure", 25 September 2017, see https://www.wltx.com/article/news/local/house-asks-sled-to-investigate-sceg-over-vc-summer-failure/478454463, accessed 24 May 2018.

408 - Thad Moore, "SCE&G faces second lawsuit seeking refunds after scuttling V.C. Summer project", *The Post and Courier*, 31 August 2017, see https://www.postandcourier.com/business/sce-g-faces-second-lawsuit-seeking-refunds-after-scuttling-v/article_ddf7cccc-8cf7-11e7-b1b8-47b4ab12f578.html, accessed 24 May 2018.

409 - SCANA, "Public Service Commission of South Carolina Defers Action on Office of Regulatory Staff Request to Suspend Revised Rates Collections", 28 September 2017, see https://www.prnewswire.com/news-releases/public-service-commission-of-south-carolina-defers-action-on-office-of-regulatory-staff-request-to-suspend-revised-rates-collections-300527997.html, accessed 24 May 2018.

410 - SCANA, "Public Service Commission of South Carolina Orders Hearing on the South Carolina Office of Regulatory Staff's Request to Reduce Rates", 20 December 2017, see https://www.prnewswire.com/news-releases/public-service-commission-of-south-carolina-orders-hearing-on-the-south-carolina-office-of-regulatory-staffs-request-to-reduce-rates-300574181.html, accessed 24 May 2018.

As a result of the filings for discovery, SCG&E were forced to provide 70,000 pages of documents to Friends of the Earth early in 2018.[411] As part of the massive document dump, was included an October 2015 report by Westinghouse that said potential radiation releases also could have resulted because contractors installed vents without putting in monitoring equipment to warn of escaping radiation. The documentation is providing evidence for the ongoing legal case against SCG&E, with a judicial ruling possible by the end of 2018.

On 10 May 2018, the South Carolina state Senate voted to repeal the 2007 BLRA that enabled the failed US$9 billion V.C. Summer nuclear construction project.[412] It is the first major reform passed by the Legislature in response to the collapse of the nuclear project. As a result of the House passing similar legislation in January 2018—which proposed to suspend all ratepayer recovery, rather than reduce it as proposed by the Senate—Dominion Energy stated that its proposed takeover of SCANA for US$7.9 billion in stock could be jeopardized by any change in the law that significantly affects the financial benefits of the merger and would create a "path for Dominion Energy to walk away."[413] On 27 June 2018, the House and Senate passed a proposal to cut temporarily SCE&G's electric rates by almost 15 percent, almost wiping out the portion of the utility's power bills that customers now pay for the two abandoned nuclear reactors.[414]

The scale of the legal challenges faced by SCG&E and Santee Cooper were highlighted in mid-May 2018, when FBI agents and U.S. Department of Justice officials spent several days in South Carolina, including at the VC Summer site.[415]

The cancellation of the V.C. Summer project, in what has been described the greatest failure in the history of South Carolina,[416] recalls 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, as can be seen from the WNISR's Global Nuclear Power Database.[417]

411 - Avery G. Wilks, Sammy Fretwell "Thousands of records tell story of failed nuclear plant, could lead to SCE&G refunds", *The State*, 19 March 2018,

412 - Ashlen Renner, "SC Senate votes to repeal 2007 law that set stage for VC Summer nuclear fiasco", *The State, 10 May 2018, see* http://www.thestate.com/news/politics-government/article210692104.html, accessed 24 May 2018.

413 - Lynn Doan, Joshua Fineman, "Dominion's $8 Billion Scana Deal Dealt Another Blow in S.C.", *Bloomberg*, 19 April 2018, see https://www.bloomberg.com/news/articles/2018-04-19/dominion-s-8-billion-scana-merger-dealt-another-blow-in-s-c, accessed 24 May 2018.

414 - Ashlen Renner, "SC lawmakers make last-minute deal to cut SCE&G power bills, pass other nuclear laws", *The State*, 27 June 2018, see https://www.thestate.com/news/politics-government/article213886594.html, acccessed 11 July 2018.

415 - Avery G. Wilks, "FBI agents flock to VC Summer site as part of probe into SC's failed nuclear project", *The State*, 15 May 2018, see http://www.thestate.com/news/politics-government/article211199484.html, accessed 24 May 2018.

416 - Cindi Ross Scoppe, "Carter's departure doesn't fix the problems at Santee Cooper. These 2 changes could", *The State*, 28 August 2017, see http://www.thestate.com/opinion/opn-columns-blogs/cindi-ross-scoppe/article169800792.html, accessed 24 May 2018.

417 - WNISR/Visionscarto/Bulletin of the Atomic Scientists, "Global Nuclear Power Database", 2017, see http://thebulletin.org/global-nuclear-power-database, accessed 5 August 2017.

FUKUSHIMA STATUS REPORT

INTRODUCTION

Seven years have passed since the Fukushima disaster began. Key developments of the past year include:

- The unloading of the spent fuel from pools and removal of debris was delayed.
- A new leukaemia case in a worker was recognized as being caused by radiation exposure during the accident remediation operations—this is not the first such recognition.
- Although the number of patients in the general population who underwent cancer surgery has increased, the Fukushima accident is still not recognized as one of the causes.
- In Fukushima Prefecture, decontamination work has been progressing, but few people have returned to their homes.

ON-SITE CHALLENGES

Current Status of Each Reactor[418]

In September 2017, the Japanese government revised the medium- and long-term roadmap on the decommissioning process for the Fukushima Daiichi nuclear power plant.[419] This has been revised every two years since December 2011 and is the fourth version.

The plan delays spent fuel removal from the fuel pools of units 1, 2 and 3 for between one and three years (see Table 7). Despite this, the government has steadfastly maintained that the decommissioning work will be completed by 30 to 40 years after the accident.

Table 7 | Schedule of Spent Fuel / Debris Removal

		2017 edition	2015 edition
Fuel removal from spent fuel pools	Start of fuel removal from Unit 1	Around FY 2023	FY 2020
	Start of fuel removal from Unit 2	Around FY 2023	FY 2020
	Start of fuel removal from Unit 3	Mid-FY 2018	FY 2017
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	FY 2019	First half of FY 2018
	Start of fuel debris retrieval at the first scheduled unit	2021	2021

Sources: Compiled by WNISR based on the following documents:

METI, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station", 2015 and 2017 editions

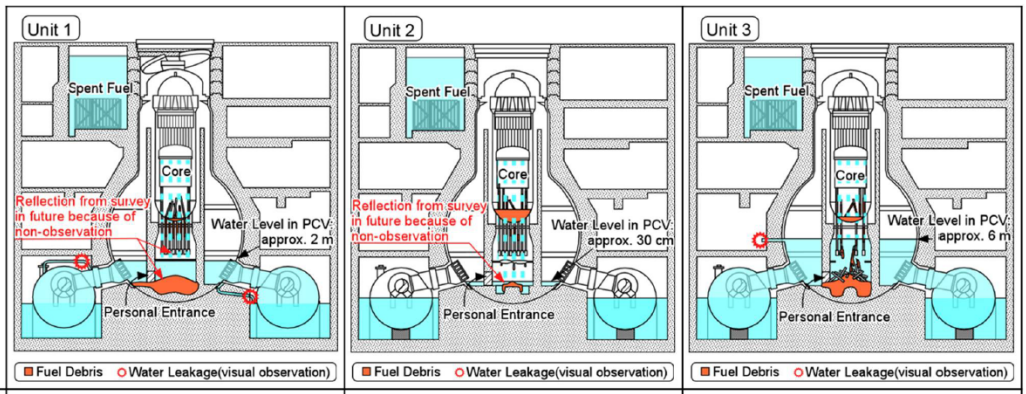
418 - METI, "Outline of decommissioning / contaminated water countermeasures", 52nd meeting of secretariat of the team for countermeasures for decommissioning and contaminated water treatment, 29 March 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/04/2-00-01.pdf, accessed 25 April 2018.

419 - 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", METI, 26 September 2017, see http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20170926_01a.pdf, accessed 25 April 2018.

Spent fuel assemblies are currently stored in the cooling pools of unit 1 to 3. There are respectively 392, 615 and 566 assemblies in the pools of units 1 to 3.[420] As of 7 May 2018, the water temperature was 25°C in fuel pool of unit 1, 26°C in unit 2 and 25°C in unit 3. Although the method of fuel removal has been decided for unit 1, this has not commenced as rubble is still being removed. As for unit 2, not even the method for fuel removal has been decided. The most progress in the implementation of the plan has been made for Unit 3 as fuel handling facilities have been installed, as of April 2018, and removal is expected to start within the current fiscal year. The removed fuel assemblies will be stored in a common, on-site, spent fuel pool.

Water injection into the reactors for cooling is ongoing. As of 7 May 2018, water injection was performed at 3 m^3/h in each reactor, the temperature inside the pressure vessels and the containment vessels are between 18 to 24 degrees Celsius. According to the government, there are no significant fluctuations in parameters, such as the pressure inside the containment vessel and the amount of radioactive material released from the containment vessel. In addition, there are no signs of cooling condition abnormality or criticality.[421]

Figure 29 | Assessment of Likely Location of Fuel Debris in Units 1–3



	Unit 1	Unit 2	Unit 3
Core Region	• Little fuel remains.	• Little fuel remains. • (Stub-shaped fuels might exist in peripheral region.)	• Little fuel remains.
RPV Lower Head	• A small amount of fuel debris is present. • A small amount of fuel debris is present in the inside and on the outer surface of the CRD housing.	• Large amount of fuel debris is present. • A small amount of fuel debris is present in the inside and on the outer surface of the CRD housing.	• Fuel debris remains on the RPV lower head partly. • A small amount of fuel debris is present in the inside and on the outer surface of the CRD housing.
Pedestal Inside	• Most of fuel debris is present.	• A small amount of fuel debris is present.	• Amount of fuel debris in Unit 3 is more than that in Unit 2.
Pedestal Outside	• Fuel debris may have spread on the pedestal outside through the personal entrance.	• The possibility of fuel debris spreading on the pedestal outside through the personal entrance is low.	• Fuel debris may have spread on the pedestal outside through the personal entrance.

* Based on the document provided by IRID and internal survey performed in 2017.

Source: Technical Strategic Plan 2017 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc., page 4-23.

420 - The source for the numbers in this and the next paragraph is Naoto Yagi, "Fukushima Daiichi Decontamination and Decommissioning: Current Status and Challenges", TEPCO, Decom2018, 18 June 2018, see https://decom2018.co.uk/wp-content/uploads/2018/06/Decom2018_Naoto_Yagi.pdf, accessed 23 July 2018.

421 - METI, "Outline of decommissioning / contaminated water countermeasures", 52nd meeting of secretariat of the team for countermeasures for decommissioning and contaminated water treatment, 29 March 2018.

In August 2017, the Nuclear Damage Compensation and Decommissioning Facilitation Organization (NDF), which conducts research and development on decommissioning technology, released an assessment of the likely location of fuel debris in the three reactors. They concluded that there is hardly any fuel debris left in the reactor pressure vessels as most of it has melted through vessels (see Figure 29).[422] In the roadmap, it is planned to examine the treatment and disposal method of fuel debris starting in 2022.

On 19 January 2018, a part of the fuel assemblies was confirmed identified through visual inspection by remote-controlled camera of the containment vessel of unit 2; it is supposed that surrounding deposits are fuel debris.[423] Namely, seven years after the accident, the specific position of fuel debris was finally established.

Contaminated Water Management

Contaminated water countermeasures are still being implemented. The latest roadmap shows a goal of reducing contaminated water production to 150 cubic meters net per day by 2020. The contamination rate was about 540 m^3/day in May 2014 and had fallen to about 140 m3/day between December 2017 and February 2018 (recorded during the drought season though).[424]

In March 2018, Tokyo Electric Power Company (TEPCO) stated that the underground temperature had dropped below 0 degrees Celsius in almost all areas of the frozen wall (land side water barrier).[425] However, the cost effectiveness of the frozen wall itself is not clear.[426] For example, TEPCO admits that the amount of contaminated water increases as rainwater flows from damaged parts of the building during heavy rain and typhoons even though there is a frozen wall.[427]

Most radioactive substances, excluding tritium, can be removed from contaminated water through various decontamination systems and is then stored in tanks. Construction of the tanks are continuing to accommodate the increase volume of treated water.[428] As of 22 March 2018, the total tank capacity of the site is about 1.1 million cubic meters, with surplus capacity of only 44,000 m^3. At the daily rate of 200 m3/day, the available capacity would

422 - Nuclear damage compensation and decommissioning facilitation corporation, Nuclear Damage Compensation and Decommissioning Facilitation Corporation, "Technical strategic plan 2017 for decommissioning of the Fukushima daiichi nuclear power station of Tokyo electric power company holdings, inc.", 31 August 2017, see http://www.dd.ndf.go.jp/en/strategic-plan/book/20171005_SP2017eFT.pdf, accessed 25 April 2018.

423 - TEPCO, "Internal Investigation of containment vessel for Fukushima daiichi nuclear power plant unit 2: Result", 1 February 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/02/3-03-02.pdf, accessed 25 April 2018.

424 - TEPCO, "Fukushima Daiichi Decontamination and Decommissioning: Current Status and Challenges", 18 June 2018.

425 - METI, "Outline of decommissioning / contaminated water countermeasures", 51st Meeting of secretariat of the team for countermeasures for decommissioning and contaminated water treatment, 1 March 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/03/2-00-01.pdf, accessed 25 April 2018.

426 - *The Asahi Shimbun*, "Fukushima 'ice wall' linchpin not living up to high hopes", 26 November 2017, see http://www.asahi.com/ajw/articles/AJ201711260031.html, accessed 25 April 2018.

427 - Contaminated water treatment committee, "Evaluation of frozen walls and future contamination countermeasures (draft)", METI, 7 March 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/osensuisyori/2018/pdf/020_04_00.pdf, accessed 2 July 2018.

428 - METI, "Progress of tank construction", 29 March 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/04/3-01-04.pdf, 52nd Meeting of secretariat of the team for countermeasures for decommissioning and contaminated water treatment, accessed 25 April 2018.

be exhausted in 220 days.[429] Consequently, there is a requirement to either further expand the storage capacity or find other solutions. TEPCO plans to add further tanks at a rate of about 500 m3 of capacity per day[430] and the capacity will be about 1.37 million tons by 2020.[431]

The Nuclear Regulatory Authority (NRA) has repeatedly called for the release into the sea of the treated—but still tritiated—water, but Fukushima Prefecture and local communities have not agreed.

Worker Exposure

In January 2018, the maximum and average external exposure doses of 7,944 workers was 10.16 mSv per month and 0.30 mSv per month respectively. Maximum (10.16 mSv per month) and average doses (0.32 mSv per month) to the 7,065 contractors were significantly higher than maximum (4.14 mSv per month) and average doses (0.14 mSv per month) to the 879 TEPCO employees.[432] TEPCO defined the exposure dose limit of workers as 20 mSv per year. Since this corresponds to about 1.7 mSv per month, TEPCO considers the current worker exposure entirely acceptable.[433]

In December 2017, another worker's leukemia was recognized as an occupational disease caused by the Fukushima accident. This worker, who is in his 40s, had worked in the Fukushima Daiichi nuclear power plant since 1994. Over a period of about 19 years, he was exposed to approximately 99 mSv, of which about 96 mSv were incurred after the Fukushima accident.[434,435]

This raises the number of workers with recognized occupational diseases as caused by the Fukushima accident to four: three leukemia cases and one thyroid cancer case.

Epidemiological studies of the workers started in FY2014. This covers about 20,000 people, who worked between 16 December 2011 to March 2014. During this time, the dose limit was raised from 100 mSv to 250 mSv per year to enable workers to undertake emergency work.[436] The results of this basic survey are not scheduled to be completed until the end of 2018.

429 - METI, "Storage situation of accumulated water (as of March 22)", 52nd Meeting of secretariat of the team for countermeasures for decommissioning and contaminated water treatment, 29 March 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/04/1-00-02.pdf, accessed 25 April 2018.

430 - METI, "Progress of tank construction", 52nd Meeting of secretariat of the team for countermeasures for decommissioning and contaminated water treatment, 29 March 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/04/3-01-04.pdf, accessed 25 April 2018.

431 - Team for countermeasures for decommissioning and contaminated water treatment, "Status of decommissioning and contaminated water countermeasure of Fukushima daiichi nuclear power plant accident", METI, 28 January 2017, (in Japanese), see http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/20170128_kyougikai_5shiryo4.pdf, accessed 2 July 2018.

432 - TEPCO, "Exposure Dose Distribution", 28 February 2018, see http://www.tepco.co.jp/en/press/corp-com/release/betu18_e/images/180228e0101.pdf, accessed 25 April 2018.

433 - METI, "Outline of decommissioning / contaminated water countermeasures", 52nd meeting of secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, 29 March 2018, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/04/2-00-01.pdf, accessed 25 April 2018.

434 - Fukushima Prefecture, "Examination results of 'Review meeting on whether or not the ionizing radiation disorders were caused by duties performed' and the recognition of an occupational disease", 3rd meeting of Fukushima Workers' Safety and Health Subcommittee, 13 December 2017, (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/250177.pdf, accessed 25 April 2018.

435 - Yoichi Yonetani, "TEPCO employee wins workers' compensation for leukemia", *The Asahi Shimbun*, 14 December 2017, see http://www.asahi.com/ajw/articles/AJ201712140025.html, accessed 25 April 2018.

436 - Radiation effects research Foundation, Website of the epidemiological study on emergency works of TEPCO's Fukushima Daiichi nuclear power plant, see https://news.rerf.or.jp/hp/top.html, accessed 25 April 2018.

OFF-SITE CHALLENGES

Current Status of Evacuation[437]

According to the Fukushima Prefecture Disaster Countermeasures Headquarters, the number of evacuees was 49,492 as of February 2018, down from 60,179 as of May 2016. 15,384 evacuees were living in the prefecture, 34,095 evacuees were living outside the prefecture, and 13 were missing.[438] Among the evacuees living in the prefecture, 3,615 people were still living in temporary housing. Among the evacuees living outside the prefecture, 13,745 people were still living with relatives or acquaintances, and 236 were in hospitals or other places.

In March 2018, the Reconstruction Agency announced the results of a survey on the intentions to return of the residents of the seven municipalities affected by the Fukushima accident.[439] According to the results of the four towns and one village in which evacuation orders have been lifted, 2.9–29.0 percent of the residents returned and 14.7–49.5 percent of the residents decided not to return. The remaining answers were "want to return", "cannot decide yet", or no answer.

In two towns in which evacuation orders have not been lifted, the percentage of residents who answered that they will not return in the future was 59.3 percent in one town and 61.1 percent in the other. Across the respondents of the seven municipalities, residents who responded that they are not going to return cited the following reasons: the foundation for their lives had now been built elsewhere and/or they are concerned about the radiation and the state of nuclear power plants decommissioning process.

The United Nations Human Rights Council (UNHRC) is concerned about the Japanese government's countermeasures for the evacuees. In November 2017, the UNHRC made four recommendations on the Japanese government's policy on evacuees from the Fukushima accident: 1. Continue providing support such as regular health monitoring; 2. Apply the Guiding Principles on Internal Displacement to all those impacted by the Fukushima Daiichi nuclear disaster; 3. Respect the rights of persons, in particular of pregnant women and children, to the highest level of physical and mental health, notably by restoring the allowable dose of radiation to the 1 mSv/year limit; 4. Guarantee access to health services for those affected by the Fukushima nuclear accident.[440]

437 - Fukushima Prefecture, "Steps for revitalization in Fukushima", 28 March 2018, (in Japanese), see http://www.pref.fukushima.lg.jp/uploaded/attachment/259959.pdf, accessed 30 April 2018.

438 - Fukushima Disaster Countermeasure Headquarters, "Flash report on the status of damage caused by the 2011 Tohoku region pacific offshore earthquake (Report number 1739)", 26 March 2018, (in Japanese), seehttp://www.pref.fukushima.lg.jp/uploaded/life/337821_820594_misc.pdf, accessed 30 April 2018.

439 - Reconstruction Agency, "Results of the residents' opinion survey at local municipalities affected by the nuclear accident (outline)", 6 March 2018, (in Japanese), see http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/ikoucyousa/29ikouchousakekka_zentai.pdf, accessed 19 August 2018.

440 - Human Rights Council, United Nations General Assembly, "Report of the Working Group on the Universal Periodic Review", Human Rights Council Thirty-seventh session, 26 February–23 March 2018, see https://documents-dds-ny.un.org/doc/UNDOC/GEN/G18/002/35/PDF/G1800235.pdf?OpenElement, accessed 7 July 2018.

Human Rights Now and Greenpeace International have also condemned the Japanese government in light of human rights violations.[441,442] In March 2018, the Japanese government commented that it will accept and follow up these recommendations, but as of June 2018[443], the government had not taken any specific measures.

No new evacuation orders were lifted in the past year. However, a change was made to the difficult-to-return zone, i.e., the area, where the annual dose exceeded 50 mSv and human occupancy will be restricted even in the future. The Reconstruction Agency revised the law in May 2017 and decided to establish a "specific reconstruction and restoration site zone," in which the evacuation order can be lifted, and people can live, within the difficult-to-return zones. Four towns announced their participation in this program and formed plans to enable evacuees to return to at least some areas by 2023.[444]

Radiation Exposure and Health Effects

Fukushima Prefecture has been continuously implementing a thyroid examination program for individuals who were 18 years old or younger at the time of the accident. Following the first round (preliminary survey) and the second round (first full survey), the third round (second full survey) is now underway. As of the end of December 2017, a total of 197 people have been diagnosed with a malignant tumor or suspected of having a malignant tumor and 161 people underwent surgery (see Table 8).[445,446] However, Fukushima Prefecture is yet to recognize any causal relationship between the occurrence of cancer in the public and the Fukushima accident.

Questions have been raised about the examination procedure itself. This survey is designed to examine cysts (bag-shaped and benign) and nodules (a lump formed in the thyroid gland by hardening, which could be benign or malignant) during the primary examination. Depending on their size and condition, a detailed examination is conducted during the secondary examination. If an embryo or nodule of a participant is diagnosed as benign during the secondary examination, it is observed by follow-up visits without treatment. However, in fact, even if those participants then develop thyroid cancer and undergo surgery during the follow-up ob-

441 - Human Rights Council, "Written statement submitted by Human Rights Now, a non- governmental organization in special consultative status", A/HRC/37/NGO/160, United Nations, Thirty-seventh session, 16 February 2018, see https://documents-dds-ny.un.org/doc/UNDOC/GEN/G18/043/29/PDF/G1804329.pdf?OpenElement, accessed 7 July 2018.

442 - Human Rights Council, "Joint written statement* submitted by Greenpeace International, a non-governmental organization in general consultative status, and the International Association of Democratic Lawyers, a non-governmental organization in special consultative status", Thirty-seventh session, United Nations, 26 February-23 March 2018, see https://documents-dds-ny.un.org/doc/UNDOC/GEN/G18/039/65/PDF/G1803965.pdf?OpenElement, accessed 7 July 2018.

443 - MOFA, "Addendum Views on conclusions and/or recommendations, voluntary commitments and replies presented by the State under review", The Government of Japan, Human Rights Council Thirty-seventh session, 1 March 2018, see https://www.mofa.go.jp/mofaj/files/000346500.pdf, accessed 7 July 2018.

444 - Reconstruction Agency, "Reconstruction and restoration plan for the specific reconstruction and restoration site zone", (in Japanese), see http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/saiseikyoten/20170913162153.html, accessed 30 April 2018.

445 - Fukushima Prefecture, "Report of Third-Round Thyroid Ultrasound Examinations (Second Full-Scale Thyroid Screening Program)", The 29th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey, 25 December 2017, see http://fmu-global.jp/download/thyroid-ultrasound-examinations-second-full-scale-thyroid-screening-program/?wpdmdl=3890, accessed 30 April 2018.

446 - Fukushima Prefecture, "Reference 3, Status of thyroid survey results", The 30th Prefectural oversight committee meeting for Fukushima health management survey, 5 March 2018, (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/247468.pdf, accessed 30 April 2018.

servation period, Fukushima Prefecture does not include them in the examination statistics.[447] Fukushima Prefecture does not reflect the results in their survey, when residents are diagnosed with cancer who voluntarily visit a medical institution or in the case of residents who visit a medical institution for diagnosis/treatment of other diseases. The reason given by the Prefecture is that they consider the protection of personal information and that it is difficult to track such residents.[448]

Therefore, Fukushima Prefecture may not be reporting the real extent of thyroid cancer cases and it is possible that the health effects of the accident are being underestimated.

Table 8 | Thyroid Cancer Statistics in the Fukushima Prefecture

Number of people diagnosed with a malignant tumor or suspected of having a malignant tumor, and surgical cases [number of people], as of 31 December 2017

Survey (Year executed)	Subjects	Number of examinees (Proportion of examinees among all subjects)	Number of examinees diagnosed with a malignant tumor or suspected of having a malignant tumor (comparison of males and females)	Number of operations performed	Surgical cases
Preliminary survey (FY 2011-FY 2013)	367,649	300,473 (81.7%)	116 (Male 39: Female 77)	102	Benign nodule: 1 Papillary carcinoma: 100 Poorly differentiated cancer: 1
Full-scale survey (Second survey) (FY 2014 - FY 2015)	381,256	270,516 (71.0)	71 (Male 32: Female 39)	52	Papillary carcinoma: 51 Other thyroid cancer: 1
Full-scale survey (Third survey) (FY 2016 - FY 2017)	336,654	191,669 (56.9)	10 (Male 6: Female 4)	7	Papillary carcinoma 7
Total	-	-	197	161	-

Source: Compiled by WNISR based on the following material:
Fukushima Prefecture, "The 30th Prefectural oversight committee meeting for Fukushima health management survey, Reference 3, Status of thyroid survey results", 5 March 2018

Food Contamination

The Ministry of Health, Labor and Welfare (MHLW) has been continuously investigating food contamination across the country. In 2017, 200 agricultural and fishery samples exceeded the contamination limits.[449] The maximum value found during this fiscal year is 11,000 Bq/kg of Cesium (total of Cs 134 and 137) that was detected in wild boar meat from Fukushima Prefecture and reported on 21 December 2017.[450]

Fukushima Prefecture had the highest number of contaminated food items: Among the total of 76 cases detected in the prefecture, there were 61 wild animal meat items, eight seafood items,

447 - Fukushima Prefecture, "Website of Radiation medical prefectural administration center, Q & A about thyroid examination", (in Japanese), see http://fukushima-mimamori.jp/qanda/thyroid-examination/thyroid-exam-other/000396.html, accessed 30 April 2018.

448 - Fukushima Prefecture, "The minutes of the 27th prefectural oversight committee meeting for Fukushima health management survey and the 7th thyroid inspection evaluation group", 5 June 2017, (in Japanese), see http://www.pref.fukushima.lg.jp/uploaded/attachment/227150.pdf, accessed 2 July 2018.

449 - MHLW, "Examination results published in FY 2017 (outline)", preliminary data, Ministry of Health, Labor and Welfare, 30 March 2018, (in Japanese), see http://www.mhlw.go.jp/file/04-Houdouhappyou-11135000-Shokuhinanzenbu-Kanshianzenka/0000170711_81.pdf, accessed 30 April 2018.

450 - MHLW, "The inspection results of radioactive substances in foods (Report 1064)", 21 December 2017, (in Japanese), see http://www.mhlw.go.jp/stf/houdou/0000188918.html, accessed 2 July 2018.

three agricultural products, and four other items. Seven years after 3/11, the number of food items exceeding the contamination limits has decreased to one sixth of the initial value (see Table 9). However, measures to limit the shipment of food types and areas in order to prevent internal radiation exposure for consumers are maintained. For example, shipment of shiitake mushroom, rice, chars, wild boar, etc. from some areas of Tohoku and Kanto regions is restricted.[451]

Table 9 | Number of Samples and Items Exceeding the Limit for Food Contamination

	Number of samples	Number of items exceeding the contamination limit (100 Bq/kg)
Before March 31, 2012	137,037	1,204
FY 2012	278,275	2,372
FY 2013	335,860	1,025
FY 2014	314,216	565
FY 2015	340,311	291
FY 2016	322,563	461
FY 2017	306,623	200

Source: Compiled by WNISR using following material:
Ministry of Health, Labor and Welfare, "Examination results published in FY 2017 (outline), as of 30 March 2018 (preliminary data)"

Decontamination[452]

According to the Ministry of the Environment (MOE), about 2.9 trillion yen (US$26.6 billion[453]) in funds have been appropriated for decontamination work up to Financial Year (FY) 2017. The term decontamination is used here to describe various measures, especially soil removal, in order to decrease contamination levels. Decontamination to pre-3/11 levels is technically impossible. Furthermore, as a result of decontamination activities, about 16.5 million cubic meters of contaminated soil has been generated. In Fukushima Prefecture, the government completed decontamination activities for the areas where contamination was intense (except for the difficult-to-return zones) by the end of March 2018. Also, decontamination activities for other prefectures and other areas of Fukushima Prefecture were completed by the end of March 2017.

The government has not defined specific target values for decontamination, but "basic principles" are stipulated by law in November 2011:

> 1) A step-by-step but prompt narrowing down of the areas where radiation exposure excluding that which comes from natural and medical sources (hereinafter referred to as the "additional radiation dose") shall aim for any area with contamination at 20 mSv/year or higher; however, it shall be borne in mind that a long-term commitment to management is required for any area with such significantly high levels of radiation.

451 - MHLW, "Shipment restrictions on foods based on the nuclear emergency preparedness measures law", as of 23 March 2018, (in Japanese), see http://www.mhlw.go.jp/file/04-Houdouhappyou-11135000-Shokuhinanzenbu-Kanshianzenka/0000198022_1.pdf, accessed 30 April 2018.

452 - Ministry of the Environment, "Efforts towards Environmental Regeneration in the Disaster Areas", 6 April 2018, see http://josen.env.go.jp/en/news/pdf/news_180409.pdf, accessed 30 April 2018.

453 - Calculated at 109 yen per US$, which is converted rate at the end of April 2018. The same hereinafter.

With regard to this target, specific goals shall be set from this point onward based on the effects of measures for decontamination of the soil, etc., the results of model projects, and so forth.[454]

2) The following shall be aimed at areas where the additional radiation dose is less than 20 mSv/year:

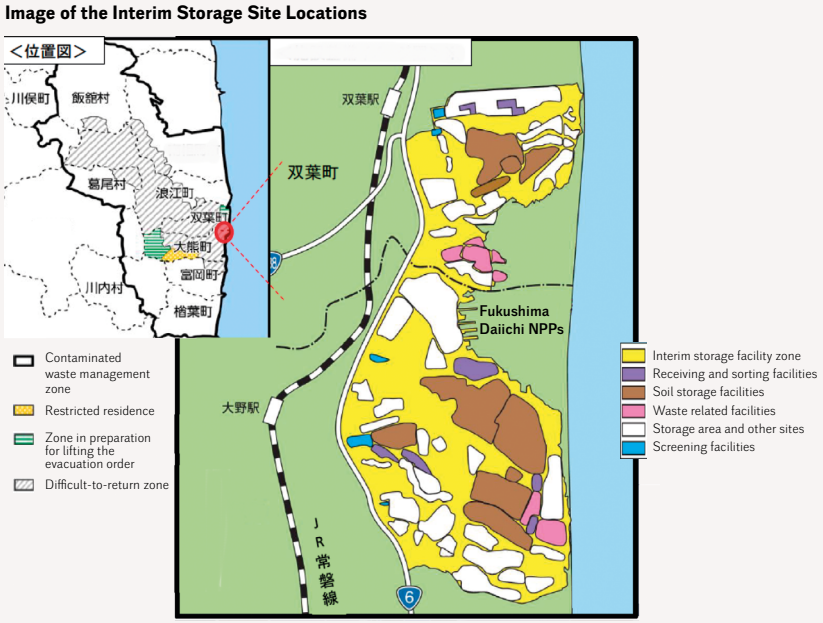
a) To reduce the additional radiation dose to 1 mSv/year or lower over the long term;

b) To reduce the additional annual radiation dose the public is exposed to by around 50% (including the physical attenuation of radioactive materials) by the end of August 2013 from the level at the end of August 2011; and

c) To reduce the additional annual radiation dose affecting children by around 60% (including the physical attenuation of radioactive materials) by the end of August 2013 from the level at the end of August 2011 by decontaminating the living environment of children, such as schools, playgrounds, etc., on a priority basis, since it is crucial to recover the environment under which children can live safely and securely.

These targets shall be reviewed from time to time based on the effects of measures for the decontamination of the soil, etc. and so forth.[455]

Figure 30 | Image of the Interim Storage Site Locations



Source: Compiled by WNISR following material: Ministry of the Environment, "Efforts towards Environmental Regeneration in the Disaster Areas", 2 March 2018

The MOE has claimed that the decontamination activities were effective. For example, it has been announced that the ambient dose rate at the height of 1 m from the ground in a residental area in Fukushima Prefecture was 1.39 µSv per hour before decontamination but it declined to 0.38 µSv per hour following decontamination.

454 - Apparently, those specific goals have not been set since.

455 - Apparently, these targets remain in place as of 2018.

Even after the completion of decontamination work, management activities continue. The government is developing plans for interim storage facilities for radioactive waste in Fukushima Prefecture. The plan is to build these facilities in the difficult-to-return zone around the Fukushima Daiichi nuclear power plant (see Figure 30[456]). Although storage has already been started in several villages, it is only an intermediate storage; the government has promised the prefecture to remove the stored contaminated soil and waste from the prefecture after 30 years of storage.

Outside Fukushima Prefecture, contamined soil is kept in each local municipality. As of the end of September 2017, the contaminated soil is stored in more than 28,000 places (over 333,000m^3 in total). This waste is intended to be stored and disposed of within each local municipality without building an intermediate storage facility.

COSTS

Regarding the decommissioning costs, a fund has been created within the Nuclear Damage Compensation and Decommissioning Facilitation Organization (NDF) and TEPCO is obliged to contribute to the fund. According to TEPCO, it is estimated that about 700 billion yen (US$6.42 billion) will be needed for decommissioning activities over the three years starting from FY 2018 to FY 2020.[457]

In March 2018, the Board of Audit of Japan conducted an accounting audit on the government's support for TEPCO concerning the Fukushima accident.[458] According to the latest estimate, TEPCO was expected to borrow about 13 trillion yen (US$119 billion), from the country for Fukushima related expenditures, and the Board estimated, it would take until FY 2051, i.e., 34 years, for this to be paid back. This loan is covered by taxes paid by the Japanese citizens.

CHAPTER CONCLUSION

The Japanese government is pretending that restoration work is proceeding at Fukushima. But this has two major problems. One is that progress is sluggish. Removal of spent fuel and fuel debris is still in the preparatory stage and has not progressed as planned. Also, the effect of the contaminated water countermeasure using the frozen wall, which cost an enormous amount of money, is unclear. Another problem is that the Government is hastening reconstruction work, while ignoring human rights. Large amounts of decontamination waste are stored in areas, where the evacuation order was lifted. In addition, radiation exposure is not entirely under control. However, residents have the choice to return or to lose all financial support—and find themselves in an inextricable situation.

456 - MOE, "Efforts towards Environmental Regeneration in the Disaster Area", Ministry of the Environment, 2 March 2018, (in Japanese), see http://josen.env.go.jp/chukanchozou/situation/pdf/current_situation_of_efforts_fukushima_180302.pdf, accessed 30 April 2018.

457 - Nuclear Damage Compensation and Decommissioning Facilitation Corporation, "Plan for reimbursement of funds for decommissioning, FY2017", 11 April 2018, (in Japanese), see http://www.dd.ndf.go.jp/jp/news_release/pdf/20180411press.pdf, accessed 30 April 2018.

458 - Board of Audit of Japan, "Report on the inspection request from the diet", 23 March 2017, (in Japanese), see http://www.jbaudit.go.jp/pr/kensa/result/30/h300323.html, accessed 30 April 2018.

DECOMMISSIONING STATUS REPORT

INTRODUCTION AND OVERVIEW

Decommissioning Worldwide

The defueling, deconstruction, and dismantling of nuclear power plants—summarized by the term decommissioning—are important steps in the life cycle of a reactor. The process is technically complex and poses major challenges in terms of the long-term planning of execution and financing. However, neither of these issues has received much attention over the past decades. Furthermore, 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 reaches the end of operational lifetimes or are already shut down permanently, the challenges of reactor decommissioning are coming to the fore, and also attract increasing public attention.

As of 1 July 2018, worldwide, there are 173 permanently shut down reactors or, 73.5 GW of capacity. If a 40-year average lifetime is assumed, a further 216 reactors will shut down by 2030 (reactors connected to the grid between 1978 and 1990); and an additional 111 will be shut down by 2057. Not accounting for the 81 reactors, which started operating already before 1978 and the additional 32 reactors in Long-term Outage (LTO). Given this expected massive shutdown of plants and the estimated US$1,000 billion value of the decommissioning market until 2050[459], there is a need for a better understanding of decommissioning policy, regulations, and markets.

Overview of Reactors with Completed Decommissioning

In the first quarter of 2018, 154 units were globally awaiting or in various stages of decommissioning, while only 19 reactors or about 6 GW had been fully decommissioned, i.e., only 8 percent of the total 74 GW withdrawn from the grid. Of these 19 reactors only 10 have been returned to greenfield sites. The average duration of the decommissioning process, independent of the chosen strategy, is around 19 years, with a very high variance: the minimum of six years for the Elk River plant, and the maximum of 42 years for CVTR (Carolinas-Virginia Tube Reactor), both in the U.S. Figure 31 provides the timelines of the 19 reactors that have completed the decommissioning process.

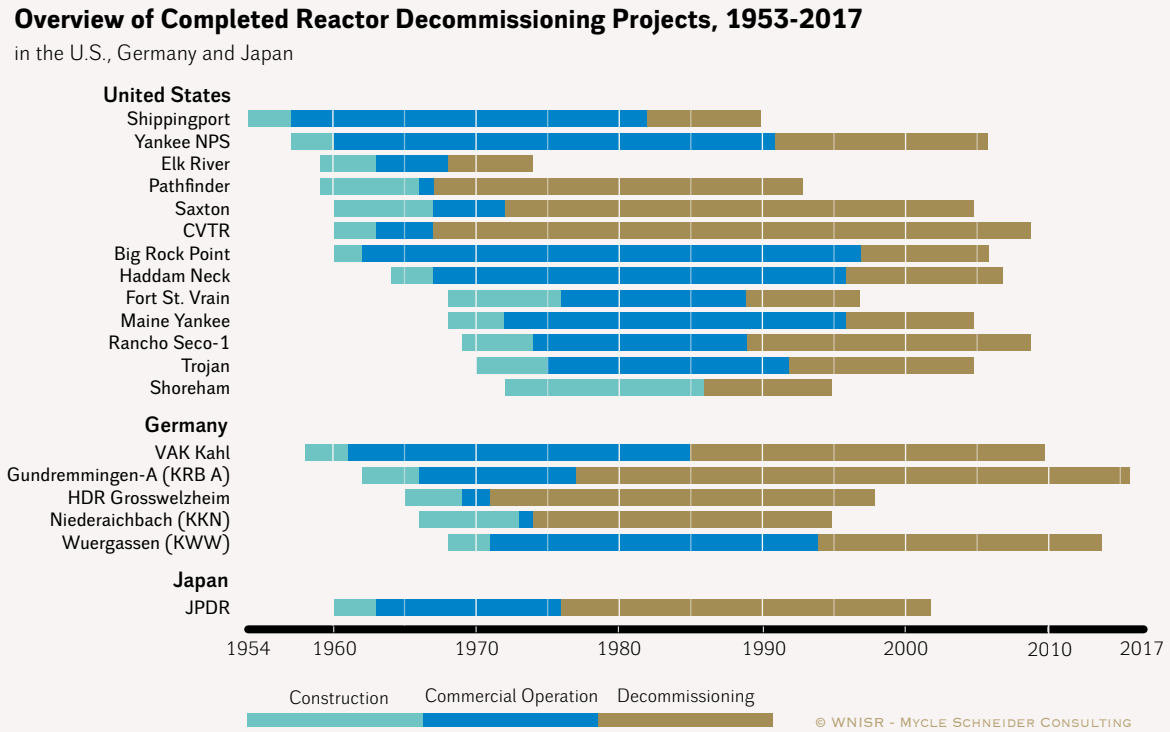
> *“only 19 reactors or about 6 GW had been fully decommissioned”*

The only countries to have completed the decommissioning process are the United States (13), Germany (5), and Japan (1). Some of the U.S. reactors are amongst the most rapidly decommissioned, such as Fort St. Vrain, Shippingport, Elk River, Maine Yankee, and Shoreham (here the

459 - IAEA, “Status of the Decommissioning of Nuclear Facilities Around the World”, 2004.

reactor building was transformed to host a gas turbine facility); yet the average duration was still 16 years, and the process took over two decades for Pathfinder and CVTR (both of which never entered operation), and Saxton. 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 actual 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). In Japan, the only reactor decommissioned was a small research reactor, whereas none of the commercial reactors has yet been decommissioned.

Figure 31 | Overview of Completed Reactor Decommissioning Projects, 1953-2017



Source: WNISR and IAEA-PRIS, 2018

Notes

The green bars represent the construction period, blue bars commercial operation, and brown bars the post-operational phase with the end of the decommissioning process. In most cases, the decommissioning process (in brown) takes longer than construction (in green) and commercial operations (in blue) combined.

In general, decommissioning takes much longer than expected, in most cases even longer than construction and operation combined. Decommissioning activities started first with the easiest projects, as nearly all these reactors are more or less small prototype or demonstration reactors with a low power output, which were not operated for a long time and hence have a smaller radiological inventory. Decommissioning of most of the oldest (first generation) reactors has not even started fully in most cases and faces particular technical and organizational challenges. In particular, the graphite-moderated, gas-cooled reactors (GCRs) in the U.K. and France are scheduled for decommissioning work for decades to come.

ELEMENTS OF NATIONAL DECOMMISSIONING POLICIES

The Decommissioning Process

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 decommissioning process moves from the outer to the inner areas of the reactor, while the degree of contamination of handled parts increases simultaneously. The technological process can generally be divided into three main stages:[460]

- The **Warm-up-stage** comprises the post-operational stage, the dismantling of systems that are not needed for the decommissioning process and the installation of the logistic in the hot zone. Also, the dismantling of higher contaminated system parts begins with e.g. steam generators and parts of the primary cooling-circuit. An indicator for the progress of this stage is the defueling of the reactor as it is crucial for the further undertaking: defueling means removing the spent fuel from the reactor core *and* the spent fuel pools.
- The **Hot-zone-stage** comprises the dismantling activities in the hot zone, i.e. dismantling of highly contaminated or activated parts, e.g. the reactor pressure vessel (RPV) and its internals (RVI), the biological shield. Furthermore, it is important to distinguish between the options of cutting up the pressure vessel on the spot or having it removed from the reactor building in one piece and dismantled later (deferred dismantling) or even disposing of it in one piece (see the U.S. case study hereunder).
- The **Ease-off-stage** comprises removal of operating systems as well as decontamination of the buildings. This stage ends ideally with the demolition of the buildings and the release of the reactor site as a greenfield for unrestricted use. The release as a brownfield is allowed in some countries, which means that the buildings can also be further used, for nuclear or other purposes.

The two basic strategies for reactor decommissioning are Immediate Dismantling (ID) and Long-Term Enclosure (LTE, sometimes called "Safe Storage").[461] In general, ID is the preferable solution as, the skills and experiences of the operating staff can be used for the decommissioning process, there is a clear line of responsibilities, and some public interest in the decommissioning process. The other advantage is that it is more likely that the money set aside to pay for decommissioning matches the necessary work. LTE usually runs the risk of losing human competences, clear lines of responsibility, and public interest, leading to dragging processes that last decades. Also, with time, risk increases that investments do not provide the level of return accounted for.

460 - Jan-Paul Seidel, Ben Wealer, "Decommissioning of nuclear power plants and storage of nuclear waste - International comparison of organizational models and policy perspectives", TU Berlin, 2016.; according to IAEA nomenclature, "decommissioning refers to the administrative and technical actions taken to remove all or some of the regulatory controls from an authorized facility so the facility and its site can be reused. Decommissioning includes activities such as planning, physical and radiological characterization, facility and site decontamination, dismantling, and materials management." See IAEA, "Decommissioning of nuclear installations", Undated, see http://www.iaea.org/topics/decommissioning, accessed 23 April 2018.

461 - A third but seldom used strategy is Entombment; here, radioactive contaminants are permanently encased on-site in materials such as concrete.

The actors on the market for decommissioning and radioactive waste management services can be public, private, or a mixture of both. In some cases, the actors that demand services are also indirectly active on the supply side of the market, e.g. in Germany. Different organizational forms for the decommissioning are conceivable and in use. The operator can carry out the decommissioning process or tender certain project parts that need highly specialized tools and expertise to private or public enterprises. For government-owned facilities, a contractor can generally manage the entire site as a prime contractor and act as the decommissioning project manager for the facility, as in the U.K. for example.

Nuclear countries have chosen quite different organizational models for the respective national decommissioning strategies, varying from specific national decommissioning strategies (e.g. in France) to a relatively free choice of the strategy for the plant operators (e.g. in the U.S.). Parallel, there are also key logistical issues that must be addressed, including supply chain bottlenecks, procurement strategies, and decommissioning strategy innovations. The U.K. had tried to tender the decommissioning of its first-generation Magnox reactors to a special purpose company, but this approach failed. Decommissioning in the U.K. is now the task of the public Nuclear Decommissioning Authority (NDA), that has set out a plan for the next century. The U.S. uses different models, amongst them private decommissioning companies looking for economies of scale by taking on several reactors. In general, there are heavy regulatory challenges to be adhered to by public authorities, and a high information asymmetry vis-à-vis operating companies.

The Financing of the Decommissioning Process

Due to its high capital intensity and long-term nature, reactor decommissioning is intimately related to financial issues. Internationally, there are many different approaches to secure the financing of the nuclear backend, but all countries more or less face the same challenges: a risk of insufficient or unavailable financial resources, underperformance of the funds, a possible bankruptcy of the operator, and foremost the underestimation of future costs.[462] Four primary approaches for accumulation and management of financial resources are observable:

- **Public budget**—State authorities take over the responsibility and with that the accumulation of financial resources via taxes, e.g. the Nuclear Decommissioning Authority in the U.K. or the German government in the case of the former East German plants.
- **External segregated fund**—The operators pay their financial obligation into a publicly controlled and managed fund. Here, private or state-owned external, independent bodies manage the funds, e.g. centralized funds for the whole industry or decentralized funds for each operator; e.g. for the operational nuclear plants in the U.K., and most of the private utilities in the U.S.
- **Internal non-segregated fund**—The operator of a nuclear facility is obliged to form and manage funds autonomously. Here, the operator manages the financial resources, which are held within their own accounts as reserves; e.g. in Germany.

462 - OECD/NEA, "Costs of Decommissioning Nuclear Power Plants", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, Publishing, 2016.

- **Internal segregated fund**—The operator feeds a self-administrated fund, which is separated from the other businesses; e.g. in France[463], Japan, and Canada.

CASE STUDIES: NORTH AMERICA, EUROPE, AND ASIA

The following section provides an in-depth review of developments in six major countries in North America, Europe, and Asia. With 136 shut down reactors (39 PWR, 36 BWR, 36 GCR, 7 PHWR, 7 FBR, 4 HTGR, 2 HWGCR, 2 HWLWR, 1 SGHWR, 2 others) in the U.S., Canada, France, Germany, Japan, and the U.K. represent almost 79 percent of the worldwide total shut down fleet. In these countries, 117 reactors are currently awaiting or in various stages of decommissioning, while 19 have completed the process.

United States

Decommissioning Monitoring

In the U.S., so far, 34 reactors (14.4 GW) have been shut down, the highest number worldwide.[464] As of 2050, at least 100 reactors are likely to be undergoing decommissioning.

Of the 34 reactors (17 PWR, 11 BWR, 2 HTGR, 1 FBR, 1 PHWR, 2 others):

- 13 units or 4.9 GW have been decommissioned (see Table 10).
- Nine units (5.3 GW), where decommissioning work is currently being performed, of which:

  - Four reactors are in "Warm-Up-Stage" (Fort Calhoun-1, Vermont Yankee, and San Onofre-2 and -3). Fort Calhoun1 (482 MW) is not yet defueled, the operator Omaha Public Power District (OPPD) estimates that by 2022 the fuel will be stored in dry casks.[465] San Onofre-2 and -3[466] are also not yet defueled but are thought to be fuel free by 2019.[467] Vermont Yankee was certified as defueled by 2014, the SNF is now dry-stored onsite.[468]

463 - In addition to the internal segregated fund for decommissioning and waste management (Article 20/II of the 2006 Waste Law) an external fund to finance the construction, operation, final closure, maintenance, and monitoring of the intermediate- or high-level waste storage or disposal installations built and operated by the radioactive waste management agency ANDRA; the latter holds and manages the fund (Article 16 of the 2006 Waste Law). Office parlementaire, "The 2006 programme act on the sustainable management of radioactive materials and wastes", Assemblée Nationale, République Française, 2006.

464 - Another shutdown 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.

465 - Omaha Public Power District, "Fort Calhoun Station Decommissioning Fuel Strategy", 2017.

466 - 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 US$4.7 billion premature shutdown costs of both units on the shoulders of the ratepayers. Then in February 2018, a settlement was reached that will see the utilities shoulder US$775 million in final costs for the closure of the power plant, overriding the 2014 agreement. 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.

467 - Southern California Edison, "Decommissioning Funding Status Report San Onofre Nuclear Generating Station Units 1, 2, and 3 and ISFSI", 28 March 2017, see https://www.nrc.gov/docs/ML1709/ML17090A152.pdf, accessed 14 August 2018.

468 - Vermont Department of Health, "Experiences with the Decommissioning of Vermont Yankee", presented at the Nuclear Decommissioning Citizens Advisory Panel Meeting, Massachusetts (U.S.), 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.

- Five reactors are in "Ease-Off-Stage" (Humboldt Bay, LaCrosse, San Onofre-1, and Zion-1 and -2).

The U.S. has also a large number of reactors in Long-Term Enclosure or LTE (12 units or 3.6 GW, including three reactors in "Entombment"). The LTE period is limited to 60 years, after which the reactor has to 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.

For the already decommissioned reactors, the process was completed on average 14 years after the permanent shutdown of the reactor. In eight reactors decommissioning was even completed under 10 years, which is short by international comparison. One reason for these short decommissioning periods is that in most cases the pressure vessel was removed and transported intact for disposal, while the internals were segmented under water or in air and dry stored on-site as greater-than-class C (GTCC) wastes along with spent nuclear fuel awaiting a federal repository.[469] In some cases, this was also done for other larger large components, e.g. the steam generators. This not only led to short decommissioning times but also modest costs ranging from US$280/kW (Trojan plant, OR) to US$1,500/kW (Connecticut Yankee, CT) of installed capacity.[470] In the case of the Trojan Plant, both, the pressure vessel and internal structures were removed intact and were shipped together with the steam generators to the Hanford site in Washington.[471] This strategy led to the overall lowest decommissioning costs in the U.S. of US$308 million. Another peculiarity of U.S. decommissioning policy is the possible use of explosives to demolish the concrete buildings.[472]

Table 10 | Current Status of Reactor Decommissioning in the U.S. (as of May 2018)

United States of America	May 2018
"Warm-up-stage"	4
of which defueled	*1*
"Hot-zone-stage"	0
"Ease-off-stage"	5
LTE	12[a]
Finished	13
of which greenfield	*6*
Shut-down reactors	**34**

a - Of which 3 reactors are in "Entombment": the DOE-reactors Piqua (Ohio), Bonus (Puerto Rico), Hallam (Nebraska).

Source: Wealer et al., 2017 and NRC, 2018[473]

Finally, as in other countries exploring decommissioning, one of the largest hurdles is the disposal of used nuclear fuel and GTCC (especially in the case of the U.S.) as facilities continue to

469 - T. S. LaGuardia, "Decommissioning of Western-type light-water nuclear reactors (LWRs)", in *Nuclear Decommissioning, Woodhead Publishing*, 2012, see https://www.sciencedirect.com/science/article/pii/B9780857091154500191, accessed 2 May 2018.

470 - 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", 2016.

471 - T. S. LaGuardia, "Decommissioning of Western-type light-water nuclear reactors (LWRs)", in *Nuclear Decommissioning, Woodhead Publishing*, 2012.

472 - Edward G. Delaney, "Decommissioning US DOE nuclear facilities", IAEA, 1985, see https://www.iaea.org/sites/default/files/27405093034.pdf, accessed 10 September 2017.

473 - NRC, "Status of the Decommissioning Program—Annual Report", 2018.

host waste on-site preventing the release as a greenfield.[474] In the U.S., the site license might be reduced to the Independent Spent Fuel Storage Installation (ISFSI); in this case, a dry storage facility for spent fuel is installed on the site. Of the fully decommissioned reactors, more than half (7) of the sites have been relicensed as ISFSI. Table 10 shows the current status of reactor decommissioning in the U.S.

Organizational Challenges

Going forward, decommissioning in the U.S. faces a challenge of efficient dismantling, and of financing the process in a context of low electricity prices placing a further strain on the competitiveness of nuclear power plants, and low provisions on behalf of the companies.[475] For the time being, decommissioning is the responsibility of the operators, who tender some of the work, especially in the "Hot-Zone-Stage" to specialized companies.[476,477] A new method that was recently used is the transfer of the decommissioning license from the operator to 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. This was done for the two Zion units in Illinois, where the operator Exelon transferred the license to EnergySolutions. U.S. company Northstar—until now with no large-scale decommissioning experience—has also entered into a purchase and sale agreement with Entergy for Vermont Yankee. The deal would include the transfer of the decommissioning trust of US$571 million, and, in 2017, Entergy has promised to add another US$125 million. In addition, NorthStar has already signed a contract with AREVA (now Orano) for the dismantling of the pressure vessel and internal structures.[478] Entergy and Northstar are proposing this model also for the Pilgrim, Indian Point and Palisades stations. These developments are problematic as limited-liability companies are only financially liable—in the case of an accident or other legal dispute—up to the value of their assets. Therefore, if the decommissioning funds are exhausted, such a third-party company could declare bankruptcy, leaving the bill for the taxpayer.[479] Indeed, EnergySolutions is already running out of money for the decommissioning of the Zion units and the State of Vermont petitions before the Atomic Safety and Licensing Board of the Nuclear Regulatory Commission (NRC) for leave to intervene in the plans and hearing request due to underestimated risks to the ratepayers.[480,481]

474 - Robert Rosner, Rebecca Lordan, "Why America should move toward dry cask consolidated interim storage of used nuclear fuel", *Bulletin of the Atomic Scientists*, 2014.

475 - Ben Wealer et al., "Nuclear Energy Policy in the United States: Between Rocks and Hard Places", IAEE Energy Forum, 2017.

476 - Conrad Cooke, Holger Spann, "Reactor vessel internals segmentation at Zion", *NEI*, 20 September 2013, see http://www.neimagazine.com/features/featurereactor-vessel-internals-segmentation-at-zion/, accessed 18 August 2018.

477 - AREVA, "Decommissioning & Dismantling", 2018, see http://us.areva.com/EN/home-3783/orano-usa-decommissioning--dismantling.html, 18 August 2018.

478 - 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 18 August 2018.

479 - D. Schlissel, et. al., "Financial Insecurity: The Increasing Use of Limited Liability Companies and Multi-Tiered Holding Companies to Own Nuclear Power Plants", STAR Foundation Riverkeeper, Ic., 2002.

480 - Julie Wernau, "Exelon: Company dismantling Zion nuclear plant is running out of money", *Chicago Tribune*, 2015, see http://www.chicagotribune.com/business/ct-zion-plant-111-biz-20150109-story.html, accessed 30 September 2017.

481 - Counsel for the State of Vermont, "State of Vermont's petition for leave to intervene and hearing request", U.S.NRC, 13 June 2017, see https://www.nrc.gov/docs/ML1716/ML17164A419.pdf, accessed 18 August 2018.

Approximately 70 percent of the U.S. utilities—generally traditional, rate-regulated utilities—collect decommissioning money from customers reactor specific in Nuclear Decommissioning Trust funds (NDT), while the remaining operators must provide financial assurance through one of the other two methods (a prepayment; a surety, insurance, or parent-company guarantee).[482] In 2016, the overall balance in the NDT was 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.[483]

There is an increasing risk that the NDT will not be sufficient to cover all the decommissioning costs in the foreseeable future due to the underestimation of future costs and a significant number of early closures. Especially the premature shutdowns due to deteriorating economic conditions appears to be a key problem 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 concludes that the cost estimates should be based on the best available knowledge from research and operational experience, but with the NRC estimation formula being based on studies conducted between 1978 and 1980, this is hardly the case. 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.[484]

Canada

In Canada, no commercial reactor has been decommissioned thus far. By 2017, 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 shut down. Although some parts have been dismantled of the shut-down 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.[485] 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 shut down only in 2007/2008 and are also in Long-Term Enclosure (LTE).[486]

The financial burden of decommissioning is to be shouldered by the operators Ontario Power Generation, Bruce Power, and New Brunswick Power. However, Ontario Power Generation and New Brunswick Power are wholly-owned public companies. 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 fun-

482 - 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, accessed 18 August 2018.

483 - Julia A. Moriarty, "2017 Nuclear Decommissioning Funding Study".

484 - Office of the Inspector General, "Audit of NRC's Decommissioning Funds Program", Defense Nuclear Facilities Safety Board, U.S.NRC, 8 June 2016, see https://www.nrc.gov/docs/ML1616/ML16160A208.pdf.

485 - CNSC, "Nuclear Power Plants—Decommissioning activities", Canadian Nuclear Safety Commission, 28 October 2016, see https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/index.cfm#DA, accessed 2 May 2018.

486 - CNSC, "Gentilly-2 Nuclear Facility", Canadian Nuclear Safety Commission, 15 September 2017, see http://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/gentilly-2-nuclear-generating-station/index.cfm, accessed 2 May 2018; and CNSC, "Pickering Nuclear Generating Station", 29 March 2018, see http://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm, accessed 11 April 2018.

ding associated with potential premature shutdown.[487] The 1996-Radioactive Waste Policy Act requires the operators to establish segregated funds to fully finance long-term waste management activities; the 2000-regulatory guide on Financial Guarantees for the Decommissioning of Licensed Activities requires that, among others, the decommissioning plan enables credible estimates of the amount of financial guarantees.[488] In certain cases, a government guarantee (at federal or provincial level) can be issued to cover the fund's underperformance.[489] The operators are not required to hold the funds in an external fund but are required to separate them from the other assets[490], 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.[491] With all the reactors in LTE and hence no decommissioned commercial reactor, cost experiences for CANDU reactors are non-existent.

United Kingdom

Decommissioning Monitoring

Since 1977, 30 reactors or 4.7 GW were shut down in the U.K., consisting mainly of the first generation of Gas-Cooled Reactors (GCRs), the so-called Magnox line (26 reactors). Decommissioning of this legacy fleet is the responsibility of the public body Nuclear Decommissioning Authority (NDA). With the exception of the Wylfa reactors, the reactors are defueled and most of the systems external to the biological shield have been removed. 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 will begin only 85 years after the initial shutdown. This strategy is controversial. Recent studies have shown that after 85 years, the larger amount 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.[492] Most of the waste will be conditioned on-site for which interim storage facilities will be built to store the waste 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). Since 2011 the focus has been on the plants in Bradwell and Trawsfynydd. Magnox Ltd., the service provider, is working towards a target of placing all the reactors into

487 - OECD/NEA, "Costs of Decommissioning Nuclear Power Plants", 2016.

488 - Wuppertal Institut, "Comparison among different decommissioning funds methodologies for nuclear installations—Examples of regulation of decommissioning financing in Non-EU countries and non-nuclear areas", Wuppertal Institut für Klima, Umwelt, Energie GmbH im Wissenschaftszentrum Nordrhein-Westfalen, on behalf of the of the Directorate-General Energy and Transport of the European Commission, 2007, see https://wupperinst.org/uploads/tx_wupperinst/EUDecommFunds_NonNuclear_NonEU.pdf, accessed 14 August 2018.

489 - OECD/NEA, "Costs of Decommissioning Nuclear Power Plants", 2016.

490 - Wuppertal Institut, "Comparison among different decommissioning funds methodologies for nuclear installations—Examples of regulation of decommissioning financing in Non-EU countries and non-nuclear areas", Wissenschaftszentrum Nordrhein-Westfalen, on behalf of the of the Directorate-General Energy and Transport of the European Commission, 2007, see https://wupperinst.org/uploads/tx_wupperinst/EUDecommFunds_NonNuclear_NonEU.pdf, accessed 14 August 2018.

491 - Ibidem.

492 - NDA, "Strategy - Effective from April 2016", Nuclear Decommissioning Authority, Nuclear Decommissioning Authority, 2016.

LTE by 2028. The current plans of the NDA indicate that it will take another 110 years to complete the core-mission of nuclear clean-up and waste management.[493]

Organizational challenges

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 (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.[494] In a recent public account, the U.K. House of Commons stated the NDA completely 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 GBP100 million to a losing consortium, and the scale of the work was drastically under-estimated.[495]

With the exception of Calder Hall 1-4, all the sites with Magnox reactors are operated by the SLC Magnox Ltd. Since 2014, Cavendish Fluor Partnership is the current PBO, but the contract officially ends in 2019. The Sellafield complex is operated by the SLC Sellafield Ltd., which is since 2016 a wholly owned subsidiary of the NDA. A detailed review concluded that the complex, technical uncertainties at the Sellafield site were less suited to the PBO model.[496] 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 sums of money involved are much greater than on other NDA sites. In July 2018, the NDA announced that Magnox Ltd will also become a subsidiary of the NDA.[497] Hence, starting 1 September 2019, decommissioning of the entire legacy fleet, with the exception of the two Dounreay fast breeders,[498]is managed by the NDA. While the NDA funding comes largely from direct government funding, a segregated fund—the Nuclear Liabilities Fund—fed by payments from the only operator EDF Energy is in place for the operational fleet.

493 - Ibidem.

494 - 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.

495 - 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.

496 - 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.

497 - 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.

498 - Here a consortium of Cavendish Nuclear, Jacobs, and AECOM owns the SLC Dounreay Site Restoration Ltd.

France

Decommissioning Monitoring

Since 1973, 12[499] reactors (8 GCR UNGG, 1 HWGCR, 2 FBR, 1 PWR) or 3.8 GW were shut down in France. Although the French utility Electricité De France (EDF) operates with 57 PWRs (plus one that is in LTO) the most standardized fleet in the world, the legacy fleet consists mainly of Gas-cooled Reactors (GCRs). French regulation states that decommissioning has to begin immediately after reactor closure, but depending on the complexity of the plant, this could mean several years up to several decades. In 2011, EDF planned to decommission its nine shut-down reactors within 25 years until 2036.[500] This ambitious plan was changed in 2016, and the timeframes considerably extended, when EDF announced a change of the GCR strategy to regulator ASN [Autorité de Sûreté Nucléaire]. 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 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 addition, EDF opts now for a dry dismantling of the reactors, mainly motivated by technological constraints due to the long immersion times of the reactors, i.e. corrosion and leak tightness.[501] According to EDF, the initial plan with the continuous flow of graphite waste and the very tight focus on the reactor core could not be implemented because the actual dismantling is technologically more complex than estimated and needs more preliminary tests than expected.[502] In addition, there is not even a theoretical disposal route for the graphite waste. ASN expects EDF to submit a detailed decommissioning plan for the next 15 years and to take a position regarding this "sudden" change in strategy.[503] It remains unclear, if the new strategy is compatible with the implication of the French policy to carry out decommissioning as fast as possible.

> *"in addition, there is not even a theoretical disposal route for the graphite waste"*

The only shut-down Pressuized Water Reactor (PWR) Chooz-A (in 1991) was defueled by 1995. The policy change in 2011 from LTE to immediate dismantling accelerated the decommissioning plans and reduced the enclosure period from 50 to only a few years.[504] Since 2014, for the first time, a pressure vessel is being dismantled in France (under water). EDF missed the ambitious target of completing decommissioning by 2016; the process is now expected to be comple-

499 - Another shutdown reactor is the military reactor G-1 on the Marcoule site – shut down in 1968 and being decommissioned ever since.

500 - Bertrand Martelet, "EDF's Expertise and Position in Nuclear Decommissioning", presented at the 1st World Nuclear Decommissioning & Waste Management Congress, 2016.

501 - Ibidem.

502 - According to EDF's previous time schedule, the critical path of the former GCR "initial decommissioning" project consisted of the graphite removal from the reactor core and the decommissioning of the reactors was already well behind in schedule in 2011. G. Laurent, "EDF Nuclear plant under decommissioning programme CIDEN organization projects achievement", presented at the Special Seminar on the 12th meeting of the Working Party on the Management of Materials from Decommissioning and Dismantling (WPDDD), Commemorating the 10th anniversary of the WPDD, 2011.

503 - In France, EDF officially uses the term "Safe Configuration" instead of LTE or Safe Storage, while in the U.K., where EDF Energy is responsible for the decommissioning of the operational GCR fleet, the company opts officially for the LTE.

504 - Policy Department on Budgetary Affairs, "Nuclear decommissioning: Management of costs and risks", European Parliament, 2013.

ted between 2020 and 2025.[505] In 2006, decommissioning of the 1,200 MW_e FBR Superphénix started.[506] The reactor is thought to enter the "hot-zone-stage" in 2018 with the dismantling of the internal structures.[507] Decommissioning of the HWR EL-4 on the Brennilis site started in 2006 and the reactor is still in the "Warm-Up-Stage" with earliest possible regulatory release set to 2028; however, this process depends on the construction of interim storage facilities and the granting of a complete dismantling license.[508] Decommissioning of the plutonium-production GCRs G-2 and G-3 on the Marcoule site is the responsibility of the French Alternative Energies & Atomic Energy Commission (CEA). The reactors are defueled, the external systems removed, parts of the buildings were demolished, and the reactors were put into LTE. The next steps, which are thought to begin in 2020 are the removal of the graphite wastes from the reactor as well as the dismantling of the latter, currently estimated to be completed sometime after 2040.[509] Decommissioning of the FBR Phénix, shut down 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.[510] Table 11 shows the current status of reactor decommissioning in France.

Table 11 | Current Status of Reactor Decommissioning in France (as of May 2018)

France	May 2018
"Warm-up-stage"	3
of which defueled	2
"Hot-zone-stage"	1
"Ease-off-stage"	0
LTE	8
Finished	0
of which greenfield	0
Shut-down reactors	**12**

Sources: Various, compiled by WNISR 2018

Organizational challenges

The decommissioning process is organized and executed by the two public entities EDF and CEA. The dismantling of the pressure vessel and internal structures of only Pressurized Water Reactor (PWR) under decommissioning (Chooz-A) was tendered to a Westinghouse-Nuvia

505 - Bertrand Martelet, "EDF's Expertise and Position in Nuclear Decommissioning", 2016.

506 - Decommissioning of the FBR Phénix is the scope of the French Alternative Energies & Atomic Energy Commission (CEA).

507 - EDF, Areva and Commissariat à l'Énergie Atomique et aux énergies alternatives, "Introduction to the French nuclear decommissioning experience", 30 June 2017, see http://www2.convention.co.jp/haishi/pdf/gay.pdf, accessed 14 August 2018.

508 - EDF, "Déconstruction du site nucléaire de Brennilis", Dossier de Presse, 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.

509 - 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.

510 - 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.

France consortium.[511] In 2016, EDF bought the waste treatment operations of the Swedish company Studsvik AB, creating the new company cyclife. Studsvik has a metal melting facility, where contaminated material is separated from the bulk metal, which would allow EDF to recycle large components instead of disposing of them. In Chooz-A, the four steam generators, primary loops, and pressurizer have been evacuated in one piece and disposed of at the very low-level radioactive waste disposal site CIRES in the Aube department.

> *“The costs for the legacy fleet have increased steadily and doubled since 2001...”*

Current cost estimates for EDFs shut-down fleet are around €6.5 billion, while EDF has only set aside €3.3 billion.[512] The costs for the legacy fleet have increased steadily and doubled since 2001, when they were estimated to be around €3.3 billion.[513] For the operational fleet EDF expects total costs of around €23 billion, which corresponds to around €300/kW of installed capacity, quite 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”.[514] The report concluded that decommissioning and clean-up will take more time, that the technical feasibility is not fully assured, and that the process will cost overall much more than EDF anticipates.

Germany

Decommissioning Monitoring

The closure of Gundremmingen-B in 2017 increased the German shut-down fleet to 29 reactors or 16.9 GW (14 PWRs, 10 BWRs, 2 HTGR, 1 FBR, 1 HWGCR). The demonstration reactor Lingen and the thorium prototype reactor THTR-300 are the only reactors in LTE. 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 longer period of time (24 years). Dismantling began immediately after its shutdown in 1988 and it was released as a greenfield site in 2010. Total costs were given as €150 million in 2010 (or ~€10,000/kW).[515] 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” only in 2016. 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

511 - Penny Hitchin, “Excavating Chooz A”, *NEI*, 6 November 2010, see http://www.neimagazine.com/features/featureexcavating-chooz-a/, accessed 5 April 2017.

512 - EDF, “Consolidated Financial Statements at 31 December 2017”, p.100.

513 - Cour des Comptes, “Le coût de production de l’électricité nucléaire - Actualisation 2014”, 2014.

514 - 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.

515 - Ursula Schönberger et al. (2013), “Atommüll: eine Bestandsaufnahme für die Bundesrepublik Deutschland ; Sorgenbericht der Atommüllkonferenz”, Arbeitsgemeinschaft Schacht Konrad e.V, 2013.

Würgassen.[516] 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". Although for both sites, the deferred dismantling strategy was chosen: The six pressure vessels were transported to the on-site interim storage facility (Zwischenlager Nord), also operated by EWN, as were 17 steam generators and parts of the primary cooling system.

All plants shut down following the Fukushima disaster in March 2011 have submitted their decommissioning proposal to the regulatory authority, but the German operators currently face several obstacles in order to be able to conclude the decommissioning process in a timely manner without excessive costs. In early 2018, there are insufficient numbers of transport and storage casks being produced to defuel the reactors. In addition, the early shutdown of reactors after 3/11 caused a high number of "special" fuel rods—not completely burnt-up fuel—in the reactor core, for which no casks have yet been approved by the regulatory authority. The defueling and subsequent interim storage cannot be achieved until the required casks are available.[517] Table 12 shows the development in the decommissioning process since 2015 as of May 2018. Only Brunsbüttel was defueled, the 12 special fuel rods were sent to Sweden and are thought to be sold to a U.S. company.[518] Mülheim-Kärlich entered the "hot-zone-stage", while Gundremmingen-B entered the "warm-up-stage."

Table 12 | Current status of reactor decommissioning in Germany (as of May 2018)

Germany	2015	May 2018
"Warm-up-stage"	10	10
of which defueled	*0*	*1*
"Hot-zone-stage"	3	4
"Ease-off-stage"	9	8
LTE	2	2
Finished	4	5
of which greenfield	*3*	*3*
Shut-down reactors	**28**	**29**

Source: Seidel and Wealer, 2016 and Bredberg, et al. 2017[519]

Organizational challenges

Germany is currently exploring large-scale decommissioning, and, with the exception of the former GDR reactors, it is currently carried out (and financed) by the utilities themselves. The legacy fleet of the former GDR is being decommissioned by EWN, a public company under

516 - Both sites cannot be released from regulatory control as the buildings are used for further decommissioning works or interim storage of wastes. Ben Wealer et al., "Stand und Perspektiven des Rückbaus von Kernkraftwerken in Deutschland (»Rückbau-Monitoring 2015«)", DIW, German Insitute for Economic Research, Berlin, TU Berlin, November 2015, (in German), see http://www.diw.de/documents/publikationen/73/diw_01.c.519393.de/diw_datadoc_2015-081.pdf, accessed 29 September 2016.

517 - See Wealer et al. Ibid. for a detailed survey of the German decommissioning process.

518 - Bundesregierung, "Frische und verunreinigte Brennelemente aus Atomkraftwerken", Drucksache 19/00479, 2018, (in German), see http://www.hubertus-zdebel.de/wp-content/uploads/2018/02/KA_MdB_Zdebel-KKK-verunreinigte_BE_Sonderst%C3%A4be_alle_AKW_Antwort_19_00479-VOE.pdf, accessed 14 August 2018.

519 - Ines Bredberg et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2016", Bundesamt für kerntechnische Entsorgungssicherheit, 2017.

control of the German Federal Ministry of Finances. The utilities, on their part, tendered the work in the "hot-zone-stage", e.g. Areva for Würgassen and Stade, EWN for Obrigheim. In 2017, Vattenfall awarded the contract to dismantle the internal structures to an Areva-EWN joint venture for its Brunsbüttel reactor with a possible option for the Krümmel plant. In January 2018, PreussenElektra awarded a decommissioning contract to ZerKon—a consortium led by the German utilities-owned waste management company GNS and Westinghouse Electric Sweden—to dismantle the internal structures of its six plants.[520]

The funding system for commercial reactors differs between the publicly-owned GDR facilities and the facilities in private ownership. For the latter provisions have to be set aside by the operator. On behalf of the government, an expert commission reviewed the financing system and provided reform proposals to meet the actual risk related to the system of internal non-segregated funds.[521] The law published in 2016,[522] led to the implementation of an external segregated fund for nuclear waste. The fund was fed by the former provisions for these tasks totaling €23 billion (US$25 billion) including a risk premium. The utilities are still responsible for decommissioning and for the conditioning of waste, but all the downstream tasks (mainly storage) will be done by public companies and paid from the fund. The responsibility as well as risks, including the financial ones in the case of insufficient set-aside funds, will have to be borne by the public, which infringes the polluter-pays-principle.[523]

Japan

As of mid-June 2018, the shut-down fleet in Japan consisted of 25 reactors or 16 GW, all of which applied for the decommissioning license, while only 13 are licensed for decommissioning, with the latest approval having been granted for the Monju reactor in March 2018.[524] The decommissioning of Tokai-1 is ongoing since 2001 and scheduled to be completed in 2025; the decommissioning of Fugen ATR is planned for the period of 20082034; Hamaoka-1 and -2 from 20092036. Genkai-1, Ikata-1, Mihama-1 and 2, Shimane-1, and Tsuruga-1 received their licenses in 2017. The decommissioning 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. If the shut-down Fukushima Daini-1-4 reactors will enter the decommissioning process is not yet official but expected. WNISR considers that they will not restart. Japan, one of the early adopters of nuclear power, has not finished the 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 in 2002.

Similar to other countries, Japan lacks experience in decommissioning—both, regarding the physical deconstruction and its financing. Japan has not yet developed a decommissioning in-

520 - *WNN*, "GNS-led consortium wins German decommissioning contract", 23 January 2018, see http://www.world-nuclear-news.org/WR-GNS-led-consortium-wins-German-decommissioning-contract-2301187.html, accessed 26 April 2018.

521 - See the chapter "Nuclear Finances a tough market environment" published in the WNISR 2017 for more details.

522 - Deutscher Bundestag, "Gesetz zur Neuordnung der Verantwortung in der kerntechnischen Entsorgung", Drucksache 768/16, 16 December 2016, (in German), see https://www.bundesrat.de/SharedDocs/drucksachen/2016/0701-0800/768-16.pdf?__blob=publicationFile&v=5, accessed 9 August 2018.

523 - Elisabeth Jänsch et al., "Wer soll die Zeche zahlen? Diskussion alternativer Organisationsmodelle zur Finanzierung von Rückbau und Endlagerung", *GAIA*, 2017.

524 - *WNN*, "Regulator approves Monju decommissioning plan", 28 March 2018, see http://www.world-nuclear-news.org/WR-Regulator-approves-Monju-decommissioning-plan-2803185.html, accessed 13 August 2018.

dustry, which provides efficient solutions applicable for a range of reactor types. The general regulation in Japan stipulates that the licensed operator of a nuclear power reactor is obliged to decommission the plant. The standard scenario in Japan includes a period of LTE of five to ten years before the hot-zone is deconstructed.

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 the expenses of decommissioning during the period of operation through surcharges on the retail price of electricity and based on the output of a facility.[525] The Fukushima disaster in 2011, however, caused the shutdown of all plants by 2014 and thus a halt in the allocation resulting in a shortage of decommissioning capital. In accordance with a Ministerial Ordinance in 2013[526], 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).

> *“For some reactors the restart option might be even more expensive than the shutdown.”*

It is likely that this strategy will increasingly appear 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 to pursue reactor restart with a possible unique reactor lifetime extension of 20 years under the new regulations and, by doing that, enriching their reserves for decommissioning, or chose the shutdown option, with the consequence of LTE in order to generate sufficient funding. For some reactors the restart option might be even more expensive than the shutdown. With no decommissioned commercial reactors and no available final waste disposal route, cost experiences are non-existent, which makes cost estimates difficult. Additionally, it remains unclear, which technical processes are included in the calculation. 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.[527] This average value is congruent with estimates published by World Nuclear News (WNN), the World Nuclear Association (WNA).[528] 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—to be similar to the U.S. cost experiences.[529] That these estimates are likely to heavily underestimate real costs is illustrated by more recent estimates for the five latest reactors slated for decommissioning, where estimates have been

525 - Ibidem.; and Chubu Electric Power Company (ed), “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.

526 - Ordinance No. 52 of the Ministry of Economy, Trade and Industry, September 30, 2013.

527 - 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”, 2015.

528 - *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.

529 - Yuhji Matsuo, et. al., “Major Issues Regarding Nuclear Power Generation Costs Assessment in Japan”, IEEJ *Energy Journal*, 2015.

significantly raised to ¥160 billion (US$1.46 billion) per reactor.[530] Another issue for the decommissioning process in Japan is that under the ministry's 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 have been abandoned.[531]

CONCLUSION ON REACTOR DECOMMISSIONING

The defueling, deconstruction, and dismantling of nuclear power plants—summarized by the term decommissioning—are important steps in the life of a reactor. These processes are technically complex and pose major challenges in terms of the long-term planning of execution and financing. However, neither of these issues has received much attention over the past decades. As an increasing number of nuclear facilities either reaches the end of their operational lifetimes or is shut down, the challenges of reactor decommissioning are coming to the fore. As of mid-2018, WNISR counts a total number of 173 permanently shut-down reactors, or 73.5 GW of capacity, while an additional 32 reactors are in LTO. If one assumes a 40-year lifetime, 216 reactors will enter the post-operational phase by 2030 (reactors built between 1978 and 1990),[532] and an additional 111 units will be shut down by 2057.

As of mid-2018, 154 units were globally awaiting or in various stages of decommissioning, while only 19 reactors, or just under 6 GW, have been fully decommissioned, i.e., only 8 percent of the total shut-down capacity (73.6 GW). Again, of these 19 reactors only 10 have been released as so-called greenfield-sites. The average duration of the decommissioning process was around 19 years, with a very high variance. The graphite-moderated, gas-cooled reactors (GCRs) in the U.K. and in France are scheduled for decommissioning for the next decades. Decommissioning of Calder Hall-1 and -2, the first commercial reactors started up in the U.K. back in 1953, will reach well into the 22nd century, while Chinon-A is currently estimated to be fully decommissioned by 2056, more than a century after construction started.

The U.S. is most advanced in decommissioning its reactors. In Germany, the nuclear phase-out is in full swing with 12 reactors in various decommissioning stages, with an additional 10 units entering the "hot-zone-stage" in the coming years. Japan will enter a difficult phase in the near future—as the first reactor pressure vessel of a commercial reactor has to be removed yet. Early nuclear countries, like the U.K., Canada, and France have not completed full decommissioning of a single reactor thus far (see overview in Table 13).

530 - *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.

531 - Tsuneo Sasai, "Japan Atomic Power in dire straits after diverting funds", *The Asahi Shimbun*, 17 November 2017, see http://www.asahi.com/ajw/articles/AJ201711170054.html, accessed 30 April 2018.

532 - 81 reactors operate already over 40 years...

Table 13 | Overview of Decommissioning Status in Six Selected Countries

Country	Shut-down reactors	Decommissioning Process				
		Warm-up	Hot Zone	Ease-off	LTE	Completed
Canada	6	0	0	0	6	0
France	12	3	1	0	8	0
Germany	29	10	4	8	2	5 [17%]
Japan	25	20[a]	0	0	0	1 [4%]
United Kingdom	30	0	0	0	30	0
United States	34	4	0	5	124	13 [38%]
Total	136	37	5	13	58	19

a - Not including the Fukushima Daini 1-4 reactors.

Sources: Various, compiled by WNISR, 2018

The country case studies also suggest that both, duration and costs have been largely underestimated. The few projects that have started encounter, in nearly all the cases, delays as well as cost increases. Especially in Europe, decommissioning experiences of large scale reactors are scarce. The U.S. have decommissioned the highest number of reactors (13), but these case studies cannot be used as a reference for other cases, e.g. the removal and consequent burial of large-scale parts as the pressure vessel is prohibited by law in other countries. By contrast, the early nuclear states, such as the U.K., France, and Canada, have not fully decommissioned a single reactor. In all the cases, interim storage facilities were needed due to missing spent nuclear fuel disposal facilities, hindering the decommissioning process or even rendering the regulatory release of the site impossible.

POTENTIAL NEWCOMER COUNTRIES

Nuclear power's contribution to the global electricity mix has declined over the past two decades, as the world's power consumption has increased, while nuclear production has largely stagnated, and other sources have shown strong growth rates.

The International Atomic Energy Agency (IAEA) assumes that to meet their prediction of more than doubling of current capacity in the higher nuclear scenario, considerable new construction will occur in existing nuclear countries, such as China, South Korea and India, but also envisages significant capacity buildup in newcomer countries.

The World Nuclear Association (WNA) suggests that there are 20 countries in which nuclear power is being planned for the first time, with an additional 20, where the nuclear option is under consideration. Notwithstanding any reality check of these assumptions, this is small compared to renewable energy, as at end of 2015, targets had been established in 173 countries at the national or state/provincial level.[533] The WNA further categorizes those countries in which nuclear power is being planned into five separate groups[534]:

- Power reactors under construction: United Arab Emirates (UAE), Belarus.
- Contracts signed, legal and regulatory infrastructure well-developed or developing: Lithuania, Turkey, Bangladesh, Vietnam (but deferred).
- Committed plans, legal and regulatory infrastructure developing: Jordan, Poland, Egypt.
- Well-developed plans but commitment pending: Thailand, Indonesia, Kazakhstan, Saudi Arabia, Chile; or commitment stalled: Italy.
- Developing plans: Israel, Nigeria, Kenya, Laos, Malaysia, Morocco, Algeria.

This section of the report will look at the countries, in which WNA considers nuclear power plants are at least 'well developed'.

UNDER CONSTRUCTION

Bangladesh

On 30 November 2017, Bangladesh officially began construction of the first unit of the Rooppur nuclear plant.[535] Unit 1 is now scheduled to begin operation in 2023 followed by unit 2 in 2024.[536] The idea of building nuclear reactors at Rooppur goes back to even before Bangladesh became an independent country, to a 1963 plan by the Pakistan Atomic Energy Commission (PAEC)

533 - REN21, "Renewables 2016—Global Status Report", Renewable Energy Policy Network for the 21st Century, 2016.

534 - WNA, "Emerging Nuclear Energy Countries", July 2018, see http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx, accessed 14 August 2018.

535 - WNISR, "Construction Start at First Nuclear Power Plant in Bangladesh", 2 December 2017, see https://www.worldnuclearreport.org/Construction-Start-at-First-Nuclear-Power-Plant-in-Bangladesh.html, accessed 29 June 2018.

536 - *NEI*, "Work begins on foundation for unit 1 of Bangladesh NPP", 6 April 2018, see http://www.neimagazine.com/news/newswork-begins-on-foundation-for-unit-1-of-bangladesh-npp-6107152/, accessed 22 April 2018.

to build one reactor in West Pakistan and one in East Pakistan.[537] The International Atomic Energy Agency (IAEA) carried out a planning study in 1974-75 and projected between approximately 1,200 and 3,000 MW of nuclear capacity in Bangladesh by 1995, with nuclear power constituting 47 percent of the country's electricity capacity in the high projection.[538] Despite this lengthy history of interest, no actual construction of nuclear plants has occurred before last year.

The current reactor deal dates back to November 2011 when the Bangladeshi Government announced that it was prepared to sign a deal with the Russian Government for two 1000 MW units—the first of which was to start up between 2017 and 2018—at a total cost of US$1.5-2 billion.[539] Since then, although negotiations have reportedly been ongoing, the startup date has been continually postponed and the expected construction cost has risen sharply.

By 2015, the Bangladeshi Finance Minister was quoted as saying the project was then expected to cost US$12.65 billion.[540] However, even this is not likely to be the final cost with suggestions that this is not a fixed price contract, but a "cost-plus-fee" contract, and "the vendor has the right to come up with any cost escalation (plus their profit margin) to be incorporated into the contract amount" and that the eventual cost of generating power would be "at least 60 percent higher than the present retail cost" of electricity in Bangladesh.[541] The size of the loan is extremely large and is roughly half of Bangladesh's outstanding external debt, estimated at US$26 billion, to which the nuclear debt will be added.[542]

The December 2015 agreement was said to be signed between the Bangladesh Atomic Energy Commission (BAEC) and Rosatom for 2.4 GW of capacity, with work then expected to begin in 2016 and operation to start in 2022 and 2023.[543] According to the deal, Russia would provide 90 percent of the funds on credit at an interest rate of Libor plus 1.75 percent. Bangladesh will have to pay back the loan in 28 years with a 10-year grace period. As in other countries, Russia has offered to take back the spent fuel for reprocessing. Site preparation is reportedly 80 percent complete.[544] In late May 2016, negotiations were concluded over the US$12.65 billion project, with Russia making available US$11.385 billion.[545] In late June 2016, the Atomic Energy Regulatory Authority, issued a site license and then a few days later the country's cabinet approved the May intergovernmental agreement.[546] In April 2017, Tass, the Russian news agency,

537 - IAEA, "Country Nuclear Power Profiles—Bangladesh", Updated 2012, see https://www-pub.iaea.org/mtcd/publications/pdf/cnpp2012_cd/countryprofiles/Bangladesh/Figures/Bangladesh%20CNPP.pdf, accessed 8 May 2018.

538 - Georg Woite, "The Potential Role of Nuclear Power in Developing Countries", IAEA Bulletin, 1975.

539 - Srinivas Laxman, "Bangladesh & Russia Sign N-Plant Deal For Two Reactors At Rooppur, Asian Scientist", *Asian Scientist*, 4 November 2011, see https://www.asianscientist.com/2011/11/topnews/rooppur-nuclear-power-project-bangladesh-russia-sign-nuclear-agreement-2011/, accessed 22 April 2018.

540 - *WNN*, "Bangladesh, Russia ink $12.65 billion Rooppur plant deal", 29 December 2015, see http://www.world-nuclear-news.org/NN-Bangladesh-Russia-ink-12.65-billion-Rooppur-plant-deal-29121501.html, accessed 22 April 2018.

541 - A Rahman, "Ruppur Nuclear Power Plant: Bangladesh's Potential Blackhole", *The Daily Star*, 31 December 2015, see http://www.thedailystar.net/op-ed/politics/ruppur-nuclear-power-plant-bangladeshs-potential-blackhole-194017, accessed 22 April 2018.

542 - Rakesh Sharma, "Is Bangladesh Ready for Nuclear?", *NIW*, 22 December 2018.

543 - *WNN*, "Bangladesh, Russia Ink $12.65 Billion Rooppur Plant Deal", 29 December 2015.

544 - *NW*, "Bangladesh will begin construction of first nuclear unit in August 2017: official", 14 April 2016.

545 - *NEI*, "Russia initials credit agreement with Bangladesh for Rooppur NPP", 30 May 2016, see http://www.neimagazine.com/news/newsrussia-initials-credit-agreement-with-bangladesh-for-rooppur-npp-4907672/, accessed 22 April 2018.

546 - *WNN*, "Bangladesh moves forward with Rooppur", 28 June 2016, see http://www.world-nuclear-news.org/NN-Bangladesh-moves-forward-with-Rooppur-2806167.html, accessed 24 April 2018.

reported that permission to start construction had been granted and that work would commence in the second half of 2017.[547] In March 2017, officials from the two countries settled on the draft of an agreement that calls for Russia to take back all the spent fuel from the project and reprocess it; the formal Inter Governmental Agreement will be signed after appropriate government bodies approve the draft.[548] Resulting waste, according to Russian legislation, will have to be repatriated to Bangladesh, but no further arrangements for that are known.

> *"growing concern about the project and lack of information over the impact on water use"*

There is growing concern about the project and lack of information over the impact on water use. Pressing concerns have also been raised over the lack of preparedness of emergency planning and possible terrorist acts against the facility.[549] Others have pointed to the unsuitability of the site, with concerns over flooding, earthquakes and shifting alluvial soil, plus water shortages and high water temperatures that could affect cooling.[550] Critics of the project also claim that Bangladesh lacks the skilled labor and adequate regulators to oversee the operation of nuclear power plant.[551] Bangladesh clearly wants help from other countries, which might explain why it appointed India's Global Centre for Nuclear Energy Partnership (GCNEP) in 2017 to oversee the development and operation of the Rooppur nuclear facilities.[552]

The project's economics have been widely questioned. Earlier in 2017, a retired nuclear engineer who had been involved in advising the Bangladesh Atomic Energy Commission (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" price of US$5,500/kW because its "negotiators didn't have the expertise to properly scrutinise the quoted price".[553]

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 in June 2014. In November 2011, the Russian and Belarusian governments agreed that Russia would lend up to US$10 billion for 25 years to finance 90 percent of the contract between Atomstroyexport and the Belarus Directorate for Nuclear Power Plant Construction.

547 - *TASS*, "Rosatom plans to launch construction of Ruppur power plant in Bangladesh", 19 April 2017, see http://tass.com/economy/942156, accessed 22 April 2018.

548 - Aminur Rasel, "Russia to take back radioactive waste of Rooppur power plant", *Dhaka Tribune*, 19 March 2017, see https://www.dhakatribune.com/bangladesh/power-energy/2017/03/18/dhaka-moscow-approve-spent-nuclear-fuel-draft-deal/, accessed 22 April 2018.

549 - Petr Topychkanov, "Why the Bangladeshi public has concerns over the Rooppur nuclear project", *Russian Beyond*, 27 February 2017, see https://www.rbth.com/blogs/south_asian_outlook/2017/02/27/why-the-bangladeshi-public-has-concerns-over-the-rooppur-nuclear-project_709866, accessed 22 April 2018.

550 - Rakesh Shama, "Is Bangladesh Ready for Nuclear?", *NIW*, 22 December 2018.

551 - *NIW*, "Bangladesh", Nuclear Intelligence Weekly, 1 December 2017.

552 - WNA, "Nuclear Power in Bangladesh", see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/bangladesh.aspx, accessed 24 April 2018.

553 - 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 22 April 2018.

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.[554] 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 August 2011, the Ministry of Natural Resources and Environmental Protection of Belarus stated that the first unit would be commissioned in 2016 and the second one in 2018.[555] However, these dates were revised, and when construction started, it was stated that the reactors will not be completed until 2018 and 2020.[556] In May 2016, the startup months were specified as November 2018 and July 2020 respectively.[557] In August 2016, the reactor pressure vessel of unit one slipped and fell two meters before hitting the ground, during installation. This lead to an eight-month delay, while it was replaced.[558] In March 2018, the head of the reactor division at the power plant said that it was expected that electricity would be supplied to the grid in the 4th Quarter of 2019 with the second one online in July 2020.[559]

The official cost of the project has increased by 26 percent, to 56 billion Russian rubles – in 2001 prices ($US\$_{2001}$1.8 billion).[560] 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,[561] that has published a list of fundamental problems of the project. These include that there have been major construction problems, that the site is considered non-suitable and that Belarus has been found to be in non-compliance with some of its obligations concerning the construction of the plant, according to the meeting of the Parties of the Espoo Convention.[562] Belarus was in 2017 also found in non-compliance with the Aarhus Convention for harassing members of civil society campaigning against the project.[563] 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

554 - *NIW*, "Belarus, Aided by Russia and Broke, Europe's Last Dictatorship Proceeds With NPP", 28 September 2012.

555 - WNA, "Nuclear Power in Belarus", October 2017, see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/belarus.aspx, accessed 21 April 2018.

556 - *WNN*, "Ostrovets plant meets construction safety rules", 7 November 2014, see http://www.world-nuclear-news.org/NN-Ostrovets-plant-meets-construction-safety-rules-07111401.html, accessed 21 April 2018.

557 - *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 21 April 2018.

558 - *NIW*, "Briefs—Belarus", 7 April 2017.

559 - *Belarus News*, "Belarusian nuclear power plant to give electricity to national power grid in Q4 2019", 28 March 2018, see http://eng.belta.by/economics/view/belarusian-nuclear-power-plant-to-give-electricity-to-national-power-grid-in-q1-2019-110418-2018/, accessed 21 April 2018.

560 - *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 21 April 2018.

561 - 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 22 April 2018.

562 - MoFA, "Fundamental problems of the Astravets Nuclear Power Plant under construction in Belarus", Ministry of Foreign Affairs of the Republic of Lithuania, 29 March 2018, see http://lv.mfa.lt/default/en/news/fundamental-problems-of-the-astravets-nuclear-power-plant-under-construction-in-belarus-, accessed 22 April 2018.

563 - UNECE, "Findings and recommendations with regard to communication ACCC/C/2014/102 concerning compliance by Belarus", United Nations, Economic and Social Council, 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 22 May 2018.

nor will it be allowed to be sold on the Lithuanian market under any circumstances".[564] The Belarussian government, in order to allay European concerns about Ostrovets submitted the project to a post-Fukushima nuclear stress test and it produced in 2017 a national report, which is currently submitted to peer-review by a commission from the European Nuclear Regulators Group (ENSREG) and the European Commission. In July 2018, the European Commission announced that the 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."[565] The next step is these recommendations need to be incorporated into the next draft of the National Action Plan.[566]

Belarus has historically been an importer of electricity from Russia and Ukraine. But in May 2018, Vice-Premier Vladimir Semashko stated: "In 2018 we stopped electric energy import, because we had upgraded our own power grid. We are self-reliant and can provide ourselves with our own electric energy."[567] In fact, Semashko claims that in the first four months of 2018, Belarus exported 0.4 TWh. The startup of the Ostrovets nuclear plant would significantly increase excess capacity. Lithuania has said it will not accept any electricity from Belarus and is trying to get is neighbors to follow the ban. Currently this has not been successful, although there has been an agreement to introducing an electricity import tax.[568] Russia is currently upgrading its grid connection between the Leningradskaya and Smolensk nuclear power stations, thus potentially also enabling a better connection of Ostrovets to the West-Russian electricity grid, circumventing the Baltic States. Vice-Premier Semashko is confident: "Our energy is cheaper, and it will be on demand on this market."[569]

Turkey

In Turkey, three separate projects are being developed with three different reactor designs and three different sets of financial sources. Despite this, in early 2018, construction formally began in the first of these projects.

Akkuyu

Some four decades after the first ideas came up for a nuclear power plant at Akkuyu, in the province of Mersin on Turkey's Mediterranean coast, construction started in April 2018, a day be-

564 - 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.

565 - ENSREG, "Belarus Stress Tests Peer Review—Executive summary", European Nuclear Safety Regulators Group, July 2018, see http://www.ensreg.eu/sites/default/files/attachments/hlg_p2018-36_156_belarus_stress_test_prt_report_-_executive_summary_0.pdf, accessed 5 July 2018.

566 - European Commission, "Comprehensive risk and safety assessments of the Belarus nuclear power plant completed", Press Release, 3 July 2018, see http://europa.eu/rapid/press-release_IP-18-4347_en.htm, accessed 4 July 2018.

567 - *Belarus News*, "Belarus ramps up electricity export in 2018", 14 May 2018, see http://eng.belta.by/economics/view/belarus-ramps-up-electricity-export-in-2018-111638-2018/, accessed 3 July 2018.

568 - *Reuters*, "Baltics to cooperate on Belarus nuclear power tax", 14 December 2017, see https://www.reuters.com/article/baltics-energy/baltics-to-cooperate-on-belarus-nuclear-power-tax-idUSL8N1OC3QD, accessed 22 April 2018.

569 - *Belarus News*, "Belarus ramps up electricity export in 2018", op.cit.

fore President Putin of Russia visited Turkey for the official launch of the project.[570] The power plant is to be implemented by Rosatom of Russia under a Build-Own-Operate (BOO) model.

> *“only two months prior to the official construction start, Rosatom’s Turkish partners quit”*

In February 2018, only two months prior to the official construction start, Rosatom’s Turkish partners quit. The consortium of private companies Cengiz Holding, Kolin Insaat Turizm Sanayi ve Ticaret et Kalyon Insaat Sanayi ve Ticaret was to hold 49 percent of the shares—quit the project.[571]

A company, JSC Akkuyu Nuclear has been established to ensure construction of the project and has been designated as the Strategic Investor. According to the establishing agreement, at least 51 percent of shares in the finished project should belong to Russian companies and up to 49 percent of shares can be available for sale to outside investors. Negotiations with potential Turkish investors continues after the three prospective partners withdrew because they expected too little benefits from the project.[572] However, Rosatom has stated that it would be able to complete the project even if it is unable to attract local investors.[573] As the Strategic Investor, the project will be able to claim tax reductions and exemptions (including from income tax and value added tax), as well as custom duties exemption.[574]

An agreement was signed in May 2010 for four VVER-1200 reactors (Generation III+), with construction originally expected to start in 2015. At the heart of the project is 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.

The CEO of Akkuyu JSC (the project company set up by Russia’s Rosatom) Alexander Superfin, said in October 2013 that the project was going to be operational by mid-2020.[575] However, further delays have occurred, as the Akkuyu JSC’s Environmental Impact Assessment was rejected by the Ministry of Environment, when it was submitted in July 2013. When it was eventually approved in December 2014, it was said that the commissioning of the first unit was likely to be in 2021.[576] As a result of these domestic developments and financing problems, it was repor-

570 - Tuvan Gumrukeu, Orhan Coskun, “Turkey grants Rosatom construction license for first unit of Akkuyu...”, *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.

571 - *AFP*, “Un consortium turc se retire du projet de la centrale nucléaire d’Akkuyu”, *Agence France Presse*, 6 February 2018, see https://www.romandie.com/news/887776.rom, accessed 4 July 2018.

572 - Rosatom, “JSC Akkuyu Nuclear designated strategic investor in Turkey”, 2 April 2018, see http://www.rosatom.ru/en/press-centre/news/jsc-akkuyu-nuclear-designated-strategic-investor-in-turkey/, accessed 20 April 2018.

573 - *Reuters*, “Russia capable of building Akkuyu plant without partners: Minister”, 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.

574 - Rosatom, “JSC Akkuyu Nuclear Designated Strategic Investor in Turkey”, 2 April 2018.

575 - Orhan Coskun, “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.

576 - *WNN*, “Akkuyu project EIA gets ministry approval”, 1 December 2014, see http://www.world-nuclear-news.org/NN-Akkuyu-project-EIA-gets-ministry-approval-01121401.html, accessed 22 April 2018.

ted in November 2015 that the operation would now occur only in 2022[577] and at an estimated budget for the two units of US$22 billion.[578] Site preparation work started in April 2015[579] and it was estimated that US$3 billion had been spent as of autumn 2015.[580] On 3 March 2017, Akkuyu JSC applied for a construction license.[581] Rosatom stated: "According to the Intergovernmental Agreement, the commissioning of the first power unit must take place no later than 7 years after the issuance of all permits for construction by the Republic of Turkey."[582]

In July 2017 the European Parliament adopted a resolution which called on the Turkish Government to halt the plans for the construction of the Akkuyu project due to its location in a region prone to severe earthquakes and called on "the Turkish Government to involve, or at least consult, the governments of its neighboring countries, such as Greece and Cyprus."[583]

In April 2018, a construction license was awarded, and the first concrete was poured, with first electricity expected to be in 2023 (the 100th anniversary of the founding of the modern state of Turkey), with all four units to be operational by 2025.[584] However, some have raised concerns over the political stability of the deal and Aaron Stein of the Washington-based Atlantic Council warned that a potential barrier to completion was the political relationship between the two countries and that "Russia has shown that it will stop construction if it's upset with Turkey."[585]

The Government of Cyprus has protested about the start of construction, citing safety concerns and that potential impact, as the power plant is only a few dozen kilometers from the Northern coast of Cyprus.[586]

See "Contracts Signed" section hereunder for information on further projects in Turkey.

United Arab Emirates

In the United Arab Emirates (UAE), construction is ongoing at the Barakah nuclear project, 300 km west of Abu Dhabi, where there are four reactors under construction. At the time of the contract signing in December 2009 with Korean Electric Power Corp., the Emirates Nuclear

577 - *Sputnik News*, "First Reactor of Turkey's Akkuyu Nuclear Plant to Start Operating by 2022", 19 November 2015, see https://sputniknews.com/middleeast/201511191030420598-akkuyu-nuclear-plant-start-2022/, accessed 22 April 2018.

578 - *Vatan*, "Russian pressed for money, Akkuyu delayed 2 years", 24 March 2015, see http://www.gazetevatan.com/ruslar-paraya-sikisti-akkuyu-2-yil-gecikecek-752934-ekonomi/, accessed 22 April 2018.

579 - *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.

580 - *Hurriyet Daily News*, "$3 billion spent on Akkuyu power plant so far: CEO", 29 September 2015, see http://www.hurriyetdailynews.com/3-bln-spent-on-akkuyu-power-plant-so-far-ceo.aspx?pageID=238&nID=89154&NewsCatID=348, accessed 22 April 2018.

581 - *WNN*, "Akkuyu project receives production licence", 16 June 2017, see http://www.world-nuclear-news.org/NN-Akkuyu-project-receives-production-licence-16061701.html, accessed 22 April 2018.

582 - Orhan Coskun, "Turkey's first nuclear plant facing further delays - sources", *Reuters*, 7 February 2014.

583 - European Parliament, "P8_TA(2017)0306, 2016 Report on Turkey European Parliament resolution of 6 July 2017 on the 2016 Commission Report on Turkey (2016/2308(INI))", 6 July 2017, see http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+P8-TA-2017-0306+0+DOC+PDF+V0//EN, accessed 22 April 2018.

584 - *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.

585 - Phil Chaffee, "Putin-Erdogan Relationship Key to Akkuyu Progress", *NIW*, 6 April 2018.

586 - *ekathimerini.com*, "Nicosia to protest construction of Akkuyu nuclear plant", 5 April 2018, see http://www.ekathimerini.com/227454/article/ekathimerini/news/nicosia-to-protest-construction-of-akkuyu-nuclear-plant, accessed 22 April 2018.

Energy Corp (ENEC), said that "the contract for the construction, commissioning and fuel loads for four units equalled approximately US$20 billion, with a high percentage of the contract being offered under a fixed-price arrangement".[587]

The original financing plan for the project was thought to include US$10 billion from the Export-Import Bank of Korea, US$2 billion from the Ex-Im Bank of the U.S., US$6 billion from the government of Abu Dhabi, and US$2 billion from commercial banks.[588] However, it later transpired that the total cost of the project is at least €24.4 billion (US$28.2 billion). The financing for this was US$16.2 billion Abu Dhabi's Department of Finance, equity financing US$4.7 billion, US$2.5 billion through a loan from the Export-Import Bank of Korea, with loan agreements from the National Bank of Abu Dhabi, First Gulf Bank, HSBC and Standards Charter making up the remainder.[589] In October 2016, Korea Electric Power Corporation (KEPCO) took an 18 percent equity stake in Nawah Energy Company that owns the four reactors, with ENEC, holding the remaining 82 percent. [590]

> *"lack of locally trained and licensed domestic personnel"*

In July 2010, a site-preparation license and a limited construction license were granted for four reactors at Barakah, 53 kilometers from Ruwais.[591] A tentative schedule published in late December 2010, and not publicly altered since, suggested that Barakah-1 would start commercial operation in May 2017 with unit 2 operating from 2018, unit 3 in 2019, and unit 4 in 2020. Construction of Barakah-1 officially started on 19 July 2012, of Barakah-2 on 28 May 2013, on Barakah-3 on 24 September 2014 and unit 4 on 30 July 2015.[592] In May 2016, ENEC stated that Barakah-1 is about 87 percent complete, with Barakah-2, -3 and -4 at 68 percent, 47 percent and 29 percent respectively.[593] As late as October 2016, Korean press was reporting unit 1 to be still scheduled for completion by May 2017.[594] Then, in May 2017, *Reuters* suggested that the startup of the first reactor was delayed, potentially until the end of 2017, due to a lack of locally trained and licensed domestic personnel.[595] In May 2017, ENEC announced it had "completed initial construction activities for Unit 1" and the "handover of all systems for commissioning"; the plant as a whole would be 81 percent complete, with Barakah-1 at 95 percent finished. At the same time, ENEC stated: "The timeline includes an extension for the start-up of nuclear operations for Unit 1, from 2017 to 2018, to ensure sufficient time for international assessments

587 - 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.

588 - Kim San-Baik, "Case Studies On Financing And Electricity Price Arrangements—The Barakah Nuclear Power Plants, The United Arab Emirates", OECD/NEA, 19 September 2013, see http://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/4_2_KIM_%20Barakah%20presentation.pdf, accessed 22 April 2018.

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

590 - *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.

591 - *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.

592 - Ibidem.

593 - *NIW*, "United Arab Emirates", 20 May 2016.

594 - Lee Hyo-sik, "KEPCO to operate UAE nuclear plant for 60 years", *The Korean Times*, 20 October 2016, see http://www.koreatimes.co.kr/www/news/biz/2016/10/123_216466.html, accessed 22 April 2018.

595 - Jane Chung, "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.

and adherence to nuclear industry safety standards, as well as a reinforcement of operational proficiency for plant personnel."[596] In March 2018, the extent of the delay was confirmed with *Nawah* reporting that the startup of Unit 1 would only be in 2019.[597] But only a few months later, in July 2018, a new delay was announced, so that startup would be in late 2019 or early 2020[598], so that commercial operation would not be undertaken until 2020, three years behind schedule. Despite this, an official ceremony was held on the 26 March 2018 to mark the end of construction of the first reactor. Apparently, the primary reason for the delay remains the lack of trained staff and the multiplicity of cultures and languages among new personnel.[599]

Korean media reported that there have been a number of serious accidents at the construction site, resulting in deaths of workers. An assessment undertaken by Bechtel, on behalf of KEPCO indicated that its "contractors largely failed to ensure worker safety".[600]

The UAE 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.[601] The nuclear share is in line with expected output from the Barakah nuclear power plant, so it seems that no further nuclear power plants are envisaged at this point. In September 2017, Government officials confirmed that there were no plans to build a second plant.[602]

There are concerns that the Barakah plant maybe a target in the ongoing conflict with the Houthi rebels based in Yemen. They have claimed, although it was denied by the Emirati state, that they had successfully fired a cruise missile at the power plant. The UAE stated that they have the defensive capabilities to deal with any such threats and that the "Barakah reactor is immune."[603]

In 2017, the UAE was the second largest investor in renewable energy in the Middle East and Africa, with US$2.2 billion in finance, a rise of 2815 percent over the previous year. This includes notably several large Solar Photovoltaic projects with a total installed capacity of 2 GW.[604] The UAE has also become the expected site of the world's largest concentrated solar plant, with an agreement to build a 700 MW project and a production price of electricity expected to be as low as US$c7.3/kWh.[605]

596 - ENEC, "ENEC Announces Completion of Initial Construction Work for Unit 1 of Barakah Nuclear Energy Plant & Progress Update Towards Safety-led Operations", Emirates Nuclear Energy Corporation, 5 May 2017, see https://www.enec.gov.ae/enec-announces-completion-of-initial-construction-work-barakah-unit-1-progress-update/, accessed 22 April 2018.

597 - Nawah, "Next phase of preparations for Barakah Unit 1 Nuclear Operations starts", Press Release, 28 May 2018, see http://www.nawah.ae/en/news/NextphaseofpreparationsforBarakah.html, accessed 29 May 2018.

598 - *Arabian Business*, "UAE further delays launch of first nuclear reactor", 4 July 2018, see https://www.arabianbusiness.com/energy/400041-uae-further-delays-launch-of-first-nuclear-reactor, accessed 8 July 2018.

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

600 - 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.

601 - 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.

602 - Amena Bahr, "UAE Abu Dhabi Unlikely to Build a Second Nuclear plant", *NIW*, 29 September 2017.

603 - *NIW*, "Briefs - Saudi Arabia", 22 September 2017.

604 - Abbas Waheed, "UAE investment in renewables rockets 2,815% during 2017", *Khaleej Times*, 20 April 2018, see https://www.khaleejtimes.com/business/energy/uae-investment-in-renewables-rockets-2815-during-2017, accessed 22 April 2018.

605 - Joshua Hill, "Dubai Awards 700 Megawatt Solar CSP Contract For Mammoth Mohammed Bin Rashid Al Maktoum Solar Park", *CleanTechnica*, 19 September 2017, see https://cleantechnica.com/2017/09/19/dubai-awards-700-mw-solar-csp-contract-mammoth-mohammed-bin-rashid-al-maktoum-solar-park/, accessed 22 April 2018.

CONTRACTS SIGNED

Egypt

In Egypt, the government's Nuclear Power Plants Authority was established in the mid-1970s, and plans were developed for 10 reactors by the end of the century. Despite discussions with Chinese, French, German, and Russian suppliers, little development occurred for several decades.

In February 2015, Russia's Rosatom and Egypt's Nuclear Power Plant Authority eventually did sign an agreement that was expected to lead to the construction and financing of two reactors and possibly two additional ones. In November 2015, an intergovernmental agreement was signed for the construction of four VVER-1200 reactors at Dabaa, 130 km northwest of Cairo. The deal was apparently worth €20-22 billion (US$23-27 billion), with Russia providing up to 90 percent of the finance,[606] to be paid back through the sale of electricity. In May 2016, it was announced that Egypt concluded a US$25 billion loan with Russia for nuclear construction.[607] According to the Egyptian official journal, the loan is to cover 85 percent of the project cost, with the total investment thus estimated at around US$29.4 billion. In March 2017, Ayman Hamza, the Egyptian Minister for Electricity, said that contracts for construction works and for training of personnel had been signed with Russia and that commercial contracts were expected to be signed later in 2017.[608] In April 2017, the Energy and Environment Committee of the Parliament began discussions about regulating nuclear construction in Egypt.[609]

In December 2017, Rosatom Director General Alexey Likhachov and Mohamed Shaker, Egypt's Energy Minister signed a notice to proceed with construction as well as an agreement that "spans the power plant's entire life cycle, i.e. 70 to 80 years".[610] The total cost of the project was now reported to be US$60 billion, US$30 billion for the 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 operating and training of personnel.[611] Russia would supply a loan of US$25 billion, at three percent interest for 85 percent of the construction cost. The Egyptian government agreed to pay back over 22 years starting in 2029.

The next two and half years will focus on the site preparation and licensing. With construction expected to take five years, the completion of the project is now expected in 2026/27.[612]

606 - *NIW*, "Cairo and Moscow Ink Deal for Four-Unit Dabaa Plant", 20 November 2015.

607 - Asma Alsharif, "Russia to lend Egypt $25 billion to build nuclear power plant", *Reuters*, 1 May 2016, see http://www.reuters.com/article/us-egypt-russia-nuclear-idUSKCN0YA1G5, accessed 23 May 2016.

608 - *NEI*, "Egypt and Russia agree on two contracts for El Dabaa NPP", 20 March 2017, see http://www.neimagazine.com/news/newsegypt-and-russia-agree-on-two-contracts-for-el-dabaa-npp-5765715/, accessed 25 April 2017.

609 - Gamal Essam El-Din, "Egypt to issue new law on construction of nuclear power stations soon", *Ahram Online*, 22 April 2017, see http://english.ahram.org.eg/NewsContent/1/64/265411/Egypt/Politics-/Egypt-to-issue-new-law-on-construction-of-nuclear-.aspx, accessed 10 May 2017.

610 - *WNN*, "'Notice to proceed' contracts signed for El Dabaa", 11 December 2017, see http://www.world-nuclear-news.org/NN-Notice-to-proceed-contracts-signed-for-El-Dabaa-1112178.html, accessed 24 April 2018.

611 - Phil Chaffee, "Rosatom Locks in $30 Billion Nuclear Deal in Egypt", *NIW*, 15 December 2017.

612 - Dan Yurman, "Egypt's $60 Billion Bet on Nuclear Energy", The Energy Collective, 23 April 2018, see https://theenergycollective.com/dan-yurman/2431718/egypts-60-billion-bet-on-nuclear-energy, accessed 24 April 2018.

However, questions have been raised as to whether the Nuclear and Radiological Regulatory Authority, will have the capacity and political independence to effectively oversee the project.[613]

Turkey

Besides Akkuyu (see above), Turkey has other nuclear projects under development including the following.

Sinop

Sinop is on Turkey's northern coast and is planned to host a 4.4 GW power plant of four units of the ATMEA reactor-design. If completed this would be the first reactors of this design, jointly developed by Japanese Mitsubishi and French AREVA.[614] In April 2015, Turkish President Erdogan approved parliament's ratification of the intergovernmental agreement with Japan.[615]

The estimated cost of the project was initially US$22 billion and involves a consortium of Mitsubishi, AREVA (now known again as Framatome), GDF-Suez (now known as Engie), and Itochu, who between them will own 51 percent of the project, with the remaining 49 percent owned by Turkish companies including the State-owned electricity generating company EÜAS.[616]

The division between the international partners remains in fact undecided. The ongoing financial problems of new-old Framatome after the absorption by EDF are affecting its ability to invest in the project, as does the review by Engie of its involvement in nuclear projects across its portfolio. Furthermore, concerns remain about site suitability given its seismic conditions, which have led to discussions about putting the station on pads to reduce possible ground movement.[617] According to AREVA, in September 2016, AREVA NP signed a "preliminary engineering contract with MHI [Mitsubishi Heavy Industry] to support the technical and cost feasibility study for the proposed construction and operation of four ATMEA-1 reactors at the Sinop site".[618] The project is complicated by the region's lack of large-scale demand and the existing coal power stations, so 1,400 km of transmission lines would be needed to take the electricity to Istanbul and Ankara.

In January 2018, an Environmental Impact Assessment application was made to the Environment and Urban Planning Ministry. If approved, it will be sent to the Inspection and Assessment Commission before being made public for comment.[619] In March 2018, reports from Japan suggest that the expected cost of the project has doubled and is now expected to be

613 - Phil Chaffee, "Rosatom Locks in $30 Billion Nuclear Deal in Egypt", *NIW*, 15 December 2017.

614 - *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.

615 - *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.

616 - *WNN*, "Turkish Utility Eyes Large Stake in Sinop Project", 12 May 2015.

617 - *NIW*, "Akkuyu's Prospects Pull Past Sinop", 22 July 2016.

618 - AREVA, "Reference Document 2006", April 2017, see http://www.sa.areva.com/finance/liblocal/docs/doc-ref-2016/AREVA_DDR2016_EN_2.pdf, accessed 22 April 2018.

619 - *Daily Sabah*, "EIA application file for Sinop nuclear power plant submitted", 14 January 2018, see https://www.dailysabah.com/energy/2018/01/15/eia-application-file-for-sinop-nuclear-power-plant-submitted, accessed 22 April 2018.

US$37.5 billion and that it would be difficult to see completion by 2023. It was suggested that the Japanese side informed the Turkish of the expected costs increase.[620] Then in April 2018, press reports from Japan suggested that Itochu would no longer be willing to participate due to the exploding cost estimates, which have risen to more than JPY5,000 billion (US$46.2 billion) from JPY2,000 billion (US$19 billion) in 2013.[621]

İğneada

In October 2015, the 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 are said to "aggressively" pursuing the contract, reportedly worth US$22-25 billion.[622] In September 2016, China and Turkey signed a nuclear co-operation agreement, a similar mechanism used to develop the other nuclear projects in the country.[623] However, the financial collapse of Westinghouse, makes their current involvement in the project unlikely.

Vietnam

A decision by the Prime Minster of Vietnam of July 2011 stated that by 2020 the first nuclear power plant will be in operation, with a further 7 GW of capacity to be in operation by 2025 and total of 10.7 GW in operation by 2030. In October 2010, Vietnam had signed an intergovernmental agreement with Russia's Atomstroyexport to build the Ninh Thuan-1 nuclear power plant, using 1200 MW VVER reactors. Construction was slated to begin in 2014, with the turnkey project being owned and operated by the state utility Electricity of Vietnam (EVN). However, numerous delays have occurred and in May 2016 a presentation from the Vietnam Atomic Energy Institute suggested that construction would not start until 2028.[624] "The national electricity development plan, approved by the government in March 2016, envisioned the "first nuclear power plant put into operation in 2028".[625] At the same time, the revised National Power Master Plan—likely the same as the "national electricity development plan—suggested a diminishing role for nuclear power from 10.1 percent to 5.7 percent by 2030.[626]

Vietnam's nuclear power 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 in-

620 - Yasuaki Oshika, "Japan's nuclear export to Turkey in doubt as costs estimate doubles", *The Asahi Shimbun*, 15 March 2018, see http://www.asahi.com/ajw/articles/AJ201803150046.html, accessed 22 April 2018.

621 - *NEI*, "Japan's Itochu pulls out of Turkish nuclear project", 30 April 2018, see http://www.neimagazine.com/news/newsjapans-itochu-pulls-out-of-turkish-nuclear-project-6133206, accessed 15 May 2018.

622 - *NEI*, "Turkey finalizes site for third NPP", 18 March 2016, see http://www.neimagazine.com/news/newsturkey-finalizes-site-for-third-npp-4843161/, accessed 26 April 2017.

623 - Hergüner Bilgen Özeke, "Turkey Looks to China for Third Nuclear Power Plant", *Lexology*, 3 January 2018, see https://www.lexology.com/library/detail.aspx?g=d0b6672d-14e1-43d0-a5b3-c9750552f521, accessed 22 April 2018.

624 - *NIW*, "Newbuild, Sobriety, Secrecy and Reluctance", 24 June 2016.

625 - *VietNamNet*, "Vietnam needs US$148 billion to develop national electricity until 2030", 20 March 2016, see http://english.vietnamnet.vn/fms/society/152739/vietnam-needs-us-148-billion-to-develop-national-electricity-until-2030.html, accessed 22 April 2018.

626 - 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 22 April 2018.

creases, concerns of safety and rising construction costs.[627] Despite this, during the past year, Vietnam has signed nuclear agreements, with Russia (July 2017)[628], China (November 2017)[629] and India (March 2018)[630].

"COMMITTED PLANS"

Lithuania

Lithuania had two large RBMK (Graphite-Moderated Reactor - Chernobyl Type) reactors at Ignalina, which were shut down in 2004 and 2009, a requirement for joining the European Union. Since then there have been ongoing attempts to build a replacement, either unilaterally or with neighboring countries. (See earlier editions of the WNISR for an annual account). However, in October 2012, a consultative national referendum on the future of nuclear power was held and 63 percent voted against new nuclear construction, with sufficient turnout to validate the result.[631] Prior to his appointment as Prime Minister, Algirdas Butkevicius stated that legislation prohibiting the project would be submitted once the new parliament convenes and that "the people expressed their wish in the referendum, and I will follow the people's will".[632] In early 2016, the Energy Minister of Lithuania, Rokas Masiulis, said that the project had been shelved indefinitely, due to unfavorable market conditions.[633] No significant changes have been reported since, whereas opposition against the Ostrovets nuclear project in Belarus, 20 km from the Lithuanian border, has increased opposition against nuclear power in Lithuania in general.

Jordan

Influential policy makers in Jordan have long desired the acquisition of a nuclear power plant. 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.[634]

In November 2009, JAEC awarded an US$11.3 million contract to Australian engineering company WorleyParsons for pre-construction consulting for Jordan's first nuclear power plant.[635] JAEC and WorleyParsons narrowed down the choices to the ATMEA-1 design from AREVA

627 - *NIW*, "Briefs - Vietnam", 28 November 2016.

628 - *WNN*, "Russia signs MOU for Vietnam nuclear research centre", 4 July 2017, see http://www.world-nuclear-news.org/NN-Russia-signs-MOU-for-Vietnam-nuclear-research-centre-0407175.html, accessed 22 April 2018.

629 - *WNN*, "China and Vietnam to cooperate on nuclear safety", 13 November 2017, see http://www.world-nuclear-news.org/RS-China-and-Vietnam-to-cooperate-on-nuclear-safety-1311175.html, accessed 22 April 2018.

630 - *WNN*, "India and Vietnam enhance nuclear cooperation", 5 March 2018, see http://www.world-nuclear-news.org/NP-India-and-Vietnam-enhance-nuclear-cooperation-0503185.html, accessed 22 April 2018.

631 - Christian Lowe, "Lithuanians send nuclear plant back to drawing board", *Reuters*, 15 October 2012, see http://www.reuters.com/article/us-lithuania-nuclear-idUSBRE89E0BW20121015, accessed 22 April 2018.

632 - *NIW*, "Lithuania—Prospective PM Wants to Scrape Visaginas", 9 November 2012.

633 - *The Baltic Course*, "Masiulis: Visaginas NPP project has been shelved for now", 20 January 2016, see http://www.baltic-course.com/eng/energy/?doc=115564, accessed 22 April 2018.

634 - Mark Hibbs, "Jordan reactor siting study to be done in 2009, JAEC says", *NW*, 27 September 2007.

635 - Ann Maclachlan, "WorleyParsons to help Jordan run program for first nuclear power plant", *NW*, volume 50, 2009,.

and Mitsubishi (as projected in Turkey); the Enhanced Candu6 (EC6) from Atomic Energy of Canada Limited; the APR-1400 from Korea Electric Power Corporation, and the AES-2006 and AES92 variants of the VVER design from Rosatom.[636] In September 2014, JAEC and Rosatom signed a two-year development framework for a project, which was projected to cost under US$10 billion and generate electricity costing US$0.10/kWh.[637]

The decline in the official probability might have to do with Russia's difficulties in funding all of Rosatom's agreements.[638] In an October 2016 interview with *Nuclear Intelligence Weekly* (*NIW*), Toukan and JAEC identified four specific companies, the Czech Republic's Skoda Praha, GE-Alstom, Russia's Power Machines, and Germany's Siemens. Toukan also said: "We're requesting technology for the conventional island, export credit financing, and, if they are willing, to have some equity in the plant...We're open to this".[639]

> *"plan to build two 1000 MW 'is now over'"*

Despite these funding problems, as late as March 2018, the nuclear industry and the U.S. Department of Energy's Energy Information Administration continued to project that construction will start in 2019 and that two 1000 MW reactors will be constructed by 2024.[640] But in May 2018, an unnamed government official revealed to *The Jordan Times* that the plan to build two 1000 MW "is now over", and that "Jordan is now focusing on small modular reactors because the large reactors place financial burden on the Kingdom and in light of the current fiscal conditions we believe it is best to focus on smaller reactors".[641] This was confirmed the following month by the Jordan Atomic Energy Commission which stated: "Jordan and Russia held a meeting last year to discuss means to move forward with the project and how to secure necessary finance for the plant... The Russians requested obtaining loans from commercial banks, which would have increased the cost of the project and the prices of generated electricity. The Jordanian government rejected the proposal".[642] This suggests not only that Jordan was unable to secure financing for the two 1000 MW proposal, but also that Russia is unable to provide low-interest financing.

Local opposition comes in particular from members of the Beni Sakher tribe that lives around the Al Amra area.[643] One member of the tribe, Hind Fayez, is a prominent parliamentarian and a noted opponent.[644] She is quoted as saying: "I will not allow the construction of the nuclear

636 - Ibidem.

637 - *NIW*, "Briefs—Jordan", 18 April 2014.

638 - Geert De Clercq, "Rosatom's global nuclear ambition cramped by Kremlin politics", *Reuters*, 26 June 2016, see https://www.reuters.com/article/us-russia-nuclear-rosatom/rosatoms-global-nuclear-ambition-cramped-by-kremlin-politics-idUSKCN0ZC0QZ, accessed 24 April 2018.

639 - Phil Choffee, "Jordan: Looking for Better Offers", *Nuclear Intelligence Weekly*, 2016.

640 - *WNN*, "Middle East nuclear power to quadruple in ten years", 6 March 2018, see http://www.world-nuclear-news.org/NP-Middle-East-nuclear-power-to-quadruple-in-ten-years-06031801.html, accessed 24 April 2018.

641 - 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.

642 - Mohammad Ghazal, "Funding issues behind scrapping nuclear deal with Russia", *Jordan Times*, 12 June 2018, see http://www.jordantimes.com/news/local/funding-issues-behind-scrapping-nuclear-deal-russia-%E2%80%94-jaec, accessed 5 July 2018.

643 - Alice Su, "Jordan faces no-nukes campaign", *Jordan Vista*, 12 November 2013, see http://vista.sahafi.jo/art.php?id=1239d21fc7d1149a328ff7421be39412498d5ef8, accessed 24 April 2018.

644 - David Schenker, "The Middle East's Next Nuclear Power?", *Politico Magazine*, 28 January 2015, see https://www.politico.com/magazine/story/2015/01/jordan-nuclear-power-114712, accessed 24 April 2018.

reactor, not even over my dead body (...). The Bani Sakher tribe also rejects the construction of the nuclear reactor in Qusayr Amra".[645] A particular concern is water requirements for the reactor, which is to come from the Al-Samra Waste Water Treatment Plant in nearby Irbid.[646] If and when the reactor is commissioned, over 20 percent of the total capacity of the Treatment Plant would be used to supply water to the reactors. The output of the Treatment Plant is currently being used for irrigation;[647] diversion of water to the reactor is, naturally, of public concern. It has been suggested that "it may well be water, the Middle East's most precious resource, rather than fiscal issues that shoves the country's nuclear hopes farther into the future".[648] Nonproliferation and regional security concerns are also adding to the calls for Jordan to forgo nuclear power, with Chen Kane, director of the Middle East program at the James Martin Center for Nonproliferation Studies stating "I think nuclear energy is a way too expensive, risky and unpredictable option" for Jordan.[649]

Then JAEC's focus seems to have turned to Small Modular Reactors (SMRs). In the last couple of years, it has signed a series of MOUs and agreements on SMRs: with Saudi Arabia's King Abdullah City for Atomic and Renewable Energy in March 2017; with Rolls Royce in November 2017; with X-energy to assess the company's 75 MW pebble bed reactor in November 2017; and with Rosatom in December 2017.[650] The most recent announcement to come from JAEC Chairman Toukan, in April 2018, is that the organization is in "serious and advanced" talks with China National Nuclear Corporation (CNNC) to build a 220 MW High Temperature Gas-Cooled Reactor (HTR) in Jordan.[651] Although SMRs could be cheaper in terms of total cost, they are expected to be more expensive on a perMW basis and would pose a range of problems such as siting.[652]

In the meanwhile, Jordan has been making rapid gains on renewable energy, being ranked first in the Middle East and North Africa in renewable and clean energy growth, according to a *Bloomberg* report.[653] The country is also expected to sign a contract for its first electricity storage project to deal with intermittency.[654]

645 - *NIW*, "Nuclear programme 'to lower electricity costs by 70%'", 30 October 2013.

646 - *Venture Magazine*, "Russian Nuclear Energy Deal Signed", 19 May 2015, see http://www.venturemagazine.me/2015/05/russian-nuclear-energy-deal-signed/, accessed 24 April 2018.

647 - *Water Technology*, "As-Samra Wastewater Treatment Plant (WWTP), Jordan", see https://www.water-technology.net/projects/as-samra-wastewater-treatment-plant-jordan/, accessed 24 April 2018.

648 - *Mining.com*, "Water shortages may end Jordan's nuclear power hopes", 18 June 2018, see http://www.mining.com/web/water-shortages-may-end-jordans-nuclear-power-hopes/, accessed 24 April 2018.

649 - Karin Laub, "Jordan eager to reach nuke deal with US", *AP*, 4 July 2016, see https://apnews.com/8ddf51fbf3004c1382f69a1795c2eef7/ap-interview-jordan-eager-reach-nuke-deal-us, accessed 24 April 2018.

650 - *WNN*, "Jordan to consider deployment of X-energy SMR", 29 November 2017, see http://www.world-nuclear-news.org/NN-Jordan-to-consider-deployment-of-X-energy-SMR-2911175.html, accessed 24 April 2018; and *NIW, "Russian Sweep in the Middle East", 15 December 2017.*

651 - Mohammad Ghazal, "Jordan, China in 'serious talks' to build gas-cooled $1b reactor", *Jordan Times*, 28 April 2018, see http://ftp.jordantimes.com/news/local/jordan-china-serious-talks%E2%80%99-build-gas-cooled-1b-reactor, accessed 8 May 2018.

652 - M.V. Ramana and Ali Ahmad, "Wishful Thinking and Real Problems: Small Modular Reactors, Planning Constraints, and Nuclear Power in Jordan", *Energy Policy*, 26 March 2016.

653 - *Jordan Times*, "'Jordan 3rd in renewable energy growth globally, 1st in region'", 11 February 2018, see http://www.jordantimes.com/news/local/jordan-3rd-renewable-energy-growth-globally-1st-region%E2%80%99, accessed 7 May 2018.

654 - Anna Shiryaevskaya, et. al., "Jordan Eyes Power Storage as Next Step in Green Energy Drive", *Bloomberg*, 23 April 2018, see https://www.bloomberg.com/news/articles/2018-04-23/jordan-eyes-power-storage-as-next-step-in-green-energy-drive, accessed 9 May 2018.

The National Energy Strategy has set a target of generating 10 percent of its electricity from renewable sources by 2020.[655] One bottleneck has been a slow rate of putting in place the grid to offer access to the renewable energy generated, but a new Green Corridor project, which will transfer power generated in south Jordan to electricity consumption centers in the central and northern regions, is under construction.[656]

Poland

Poland planned the development of a series of nuclear power stations in the 1980s and started construction of two VVER-1000/320 reactors in Żarnowiec on the Baltic coast, but both construction and further plans were halted following the Chernobyl accident. In 2008, however, 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 includes proposals to build 6 GW of nuclear power capacity with the first reactor starting up by 2024.[657] The reactor types under consideration include AREVA's EPR, Westinghouse's AP1000, and Hitachi/GE's ABWR.

In January 2013, the Polish utility PGE (Polska Grupa Energetyczna) had 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.[658] At that time, the project was estimated at US$13–19 billion, site selection was to have been completed by 2016, and construction was to begin in 2019.[659] A number of vendors, including AREVA, Westinghouse, and GE-Hitachi, all lobbied Warsaw aggressively.[660] PGE formed a project company PGE EJ1, which also has a ten percent participation each of the other large Polish utilities, Tauron Polska Energia and Enea, as well as the state copper-mining firm KGHM. In January 2014, PGE EJ1 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.[661] That did not happen.

In December 2017, the rating agency Fitch, warned that "if the utilities decide to get involved in building the nuclear power plant and put it on their balance sheets then certainly we will have a close look as this may be negative for the ratings." This is because Polish utilities are already "substantially leveraged" and the massive cost of nuclear investment would be proble-

655 - International Trade Administration, "Jordan - Renewable Energy", U.S. Department of Commerce, 23 February 2017, see https://www.export.gov/article?id=Jordan-Renewable-Energy, accessed 7 May 2018.

656 - Olivia Cuthbert, "Jordan is powering a major shift to clean energy", *Arab News*, 15 September 2017, see http://www.arabnews.com/node/1161891/business-economy, accessed 8 May 2018.

657 - Polish Ministry of Economy, "Polish Nuclear Power Programme", National Atomic Energy Agency, January 2014 see http://www.paa.gov.pl/sites/default/files/PPEJ%20eng.2014.pdf, accessed 17 August 2018.

658 - *NIW*, "Briefs-Poland", 8 February 2013.

659 - *The Economist*, "Polish Energy, Going nuclear", 31 January 2014, see http://www.economist.com/blogs/easternapproaches/2014/01/polish-energy, accessed 24 April 2018.

660 - *NEI*, "Potential and Existing Global Nuclear Newbuild Projects", 25 April 2014.

661 - *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 24 April 2018.

matic. Furthermore, the agency suggested that offshore wind, with falling technology costs would be more economic.[662]

The Polish General Directorate for the Environment (GDOS) started, in December 2015, the scoping phase for the Environmental Impact Assessment for the first Polish nuclear power station with a notification to states within 1,000 km from the proposed three sites. Directly after the start of this scoping phase, PGE EJ1 informed GDOS that it was withdrawing one of the three proposed sites, at Choczewo, because of the potential impacts on protected nature areas. In March 2017, PGE EJ1 began, again, environmental assessment and site selection at only two sites, both in the Northern province of Pomerania due to be completed in 2020.[663]

However, the decisions have not been taken, and in late 2017, the Energy Minister, Krzysztof Tchorzewski, 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.[664] The Government, in January 2018, announced that it would decide during the year, if it did proceed with nuclear power, with a decision "definitely, in the first half".[665] That did not happen.

"WELL DEVELOPED PLANS"

Chile

There seems little to indicate that Chile is actively developing nuclear power. The World Nuclear Association (WNA) stated that in 2010 the Energy Minister had said that the first nuclear plant of 1100 MWe should be operating in 2024, joined by three more by 2035 and that a public-private partnership is proposed to build the first plant, with a tender to be called in 2016.[666] However, plans have not developed significantly since then.

According to the Chilean Nuclear Energy Commission, they continue to evaluate the feasibility of building a nuclear power plant although a "political decision has been postponed".[667]

In December 2015, the Government published the document Energy 2050: Chile's Energy Policy, as a long-term energy policy with a clear map of the Chilean energy sector to 2050, which makes clear that nuclear energy is not an option at the present time.[668]

662 - Agnieszka Barteczko, Anna Koper "Funding nuclear project could hit Polish utilities' ratings: Fitch", *Reuters*, 8 December 2017, see https://www.reuters.com/article/us-poland-nuclear/funding-nuclear-project-could-hit-polish-utilities-ratings-fitch-idUSKBN1E21YM, accessed 30 June 2018.

663 - *NEI*, "Site Studies begin for Poland's first NPP", 12 April 2017, see http://www.neimagazine.com/news/newssite-studies-begin-for-polands-first-npp-5784946/, accessed 24 April 2018.

664 - Wojciech Zurawski, Agnieszka Barteczko "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 24 April 2018.

665 - Agnieszka Barteczko, "Poland to decide later this year on building nuclear plant", *Reuters*, 29 January 2018, see https://www.reuters.com/article/us-poland-nuclear/poland-to-decide-later-this-year-on-building-nuclear-plant-idUSKBN1FI1Q8, accessed 30 June 2018.

666 - 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.

667 - Jerson R. Reyes, "Technology Assessment for Embarking Countries", Chilean Nuclear Energy Commission, 24 June 2013, Presentation at the Technical Meeting on Technology Assessment for Embarking Countries, IAEA, Vienna (Austria), see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-06-24-06-28-TM-NPTD/6-chile.pdf, accessed 26 April 2017.

668 - IAEA, "Chile—Country Nuclear Power Profiles", International Atomic Energy Agency, Updated 2018, see https://cnpp.iaea.org/countryprofiles/Chile/Chile.htm, accessed 24 April 2018.

Chile is the site of Latin America's first commercial-scale concentrated solar power project, with a 110 MW facility at Dominador. In October 2017, the National Energy Commission announced the results of the renewable auctions, with the average solar Photovoltaic bid coming in at US$25/MWh, with the lowest bid, from ENEL (Ente Nazionale per l'energia elettrica) of Italy at US$21.5/MWh. The average electrical energy costs procured via national energy project auctions have fallen 75 percent since the first tender of this type was conducted in 2015.[669]

Indonesia

Since the mid-1970s, Indonesia has discussed and brought forward plans to develop nuclear power, releasing its first study on the introduction of nuclear power, supported by the Italian government, in 1976. The analysis was updated in the mid-1980s with help from the International Atomic Energy Agency (IAEA), the United States, France and Italy. Numerous discussions took place over the following decade, and by 1997 a Nuclear Energy Law was adopted that gave guidance on construction, operation, and decommissioning. A decade later, the 2007 Law on National Long-Term Development Planning for 2005–25 stipulated that between 2015 and 2019, four units should be completed with an installed capacity of 6 GW.[670] In July 2007, Korea Electric Power Corp. (KEPCO) and Korea Hydro & Nuclear Power Co. (KHNP) signed a memorandum of understanding with Indonesia's PT Medco Energi Internasional to undertake a feasibility study for building two 1000 MW units at a cost of US$3 billion. Then, in December 2015, the Indonesian government pulled the plug on all nuclear plans, even for the longer-term future. Trade journal *Nuclear Engineering International* cited the Energy and Mineral Resources Minister Sudirman Said: "We have arrived at the conclusion that this is not the time to build up nuclear power capacity. We still have many alternatives and we do not need to raise any controversies."[671]

According to the IAEA, in 2017, the Indonesian government continues to develop a roadmap for nuclear energy development, but that nuclear energy is "a last resort in the national energy policy".[672] Despite this research is ongoing and in March 2018, the National Nuclear Energy Agency launched a roadmap for the development of the design of a domestic Small Modular Reactor, which was due to completed by the end of the year.[673]

Kazakhstan

Kazakhstan is the world's largest producer of uranium, with about 40 percent of the global total. It operated a small fast breeder reactor, the BN 350 at Aktau, between 1972-1999. A num-

669 - Andrew Burger, "Chile's 24x7 Concentrating Solar Power Plus Storage Project is Back on Track", *Solar Magazine*, 4 June 2018, see https://solarmagazine.com/chiles-24x7-concentrating-solar-power-plus-storage-project-is-back-on-track/, accessed 5 July 2018.

670 - Hanan Nugroho, "Development of Nuclear Power in Indonesia: Stop or Go?", *Jakarta Post*, 5 May 2010, see http://www.thejakartapost.com/news/2010/05/05/development-nuclear-power-indonesia-stop-or-go.html, accessed 26 April 2017.

671 - *NEI*, "Indonesia rules out nuclear as major power source", 14 December 2015, see http://www.neimagazine.com/news/newsindonesia-rules-out-nuclear-as-major-power-source-4752814, accessed 15 December 2015.

672 - IAEA, "Indonesia—Country Nuclear Power Profiles", Update 2017, see https://cnpp.iaea.org/countryprofiles/Indonesia/Indonesia.htm, accessed 24 April 2018.

673 - *WNN*, "Progress with Indonesian SMR project", 16 March 2018, see http://www.world-nuclear-news.org/NN-Progress-in-Indonesian-SMR-project-1603184.html, accessed 30 June 2018.

ber of countries, including Russia, Japan, South Korea, and China have signed co-operation agreements for the development of nuclear power. In 2014, President Nursultan Nazarbayev, used his State of the Nation address to highlight the need to develop nuclear power. Since then, negotiations have continued, particularly with Toshiba-Westinghouse of Japan and Rosatom of Russia.[674] However, in October 2015, the Vice Minister of Energy Bakhytzhan Dzhaksaliyev said that finding a suitable site and strategic partner may take two to three years.[675] In December 2015, a draft Atomic Energy Law was referred to the Senate, in order to address, licensing, security, environmental protection rules and standards.[676]

An April 2016 joint declaration by the energy ministers of Kazakhstan and the U.S. notes that the 2016 work plan "encourages the use of alternative energy sources in Kazakhstan, reduces emissions, and enhances nuclear safety".[677] In December 2016, the government announced that it was undertaking research into five different locations for a new nuclear power plant and that a Gen III or Gen III+ was their favored design.[678] In August 2017, Kazakhstan and the U.S. signed a nuclear cooperation agreement. According to Kazakh Energy Minister Kanat Bozumbayev, the agreement aims to "focus on cooperation in such areas as the peaceful use of nuclear energy, containment of carbon dioxide, sustainability of energy systems, opening and expansion of energy markets, as well as the non-proliferation of nuclear weapons and security".[679] And in more concrete terms, as reported by the *Astana Times*, "the Kazakh side hopes to continue joint work on decommissioning of the BN-350 reactor to ensure radiation safety of the regions and strengthen the non-proliferation regime."[680] No mentioning of new-build.

Saudi Arabia

In 2012, the IAEA suggested that in 2013 the Kingdom of Saudi Arabia might start building its first nuclear reactor.[681] The King Abdullah City for Atomic and Renewable Energy (KA-CARE) had earlier been set up in 2010 to advance this agenda, and in June 2011, the coordinator of scientific collaboration at KA-CARE announced plans to construct 16 nuclear power reactors over the next 20 years at a cost of more than 300 billion riyals (US$80 billion). The first two reactors were planned to be online ten years later and then two more per year until 2030.

674 - *WNN*, "Russia and Kazakhstan to ink nuclear power accord this year", 2 March 2016, see http://www.world-nuclear-news.org/NP-Russia-and-Kazakhstan-to-ink-nuclear-power-accord-this-year-02031601.html, accessed 24 April 2018.

675 - *Tengri News*, "Kazakhstan to define location and strategic partners for its first nuclear power plant in 2-3 years", 23 October 2015, see https://en.tengrinews.kz/industry_infrastructure/Kazakhstan-to-define-location-and-strategic-partners-for-its-262679/, accessed 24 April 2018.

676 - Government of the Republic of Kazakhstan, "Draft law on use of nuclear energy, as amended, referred to Senate", 21 December 2015, see http://www.government.kz/en/novosti/29961-draft-law-on-use-of-nuclear-energy-as-amended-referred-to-senate.html, accessed 24 April 2018.

677 - U.S.DOE, "Kazakhstan - United States Special Commission on Energy Partnership", 6 April 2016, see https://www.energy.gov/articles/kazakhstan-united-states-special-commission-energy-partnership, accessed 24 April 2018.

678 - *NEI*, "Kazakhstan considers five possible NPP sites", 1 December 2016, see http://www.neimagazine.com/news/newskazakhstan-considers-five-possible-npp-sites-5685167/, accessed 24 April 2018.

679 - Dana Omirgazy, "Kazakhstan, US agree to cooperate on nuclear energy", *The Astana Times*, 30 August 2017, see https://astanatimes.com/2017/08/kazakhstan-us-agree-to-cooperate-on-nuclear-energy/, accessed 4 July 2018.

680 - *The Astana Times*, "Kazakhstan, US agree to cooperate on nuclear energy", 30 August 2017.

681 - Lucas W. Hixson, "IAEA – Vietnam and 4 other countries to incorporate nuclear energy after Fukushima", *Enformable.com*, 24 February 2012, see http://enformable.com/2012/02/iaea-vietnam-and-4-other-countries-to-incorporate-nuclear-energy-after-fukushima/, accessed 26 April 2017.

During 2015, new co-operation agreements were signed with France, Russia, China and South Korea. The latter seemed to be the most advanced and with proposals for the building of two "smart" reactors and ongoing research and collaboration.[682] A further Memorandum of Understanding (MoU) was signed in November 2016 to strengthen cooperation on nuclear safety and regulations. While in March 2017, a cooperation agreement was signed with CNEC on the development of high-temperature gas cooled reactors.[683]

In a reiterated push for the deployment of nuclear a new domestic target of 17.6 GW by 2021 has been put forward. In March 2018, the Government approved a national nuclear program, which is said to include a shortlist of bidders (China, France, Russia, South Korea and United States) with reports suggest that contracts for the construction of two reactors expected in 2018,[684] and planned commissioning in 2027.[685] The five vendors had been requested to supply information on financing frameworks as well as technical information. Amongst the bidders, KEPCO is thought to be in a strong position, given its experience in the UAE, although Russia is also in contention due to a track record of offering finance. The French, who are likely to offer the European Pressurized Water Reactor (EPR)—with only one reactor in China newly commissioned—and along with China (Hualong-One) are proposing relatively untested designs and so may be viewed less favorably, as is the U.S. bid, using the bankrupt Westinghouse technology.[686] The President of the KA-CARE has also been reported as saying that an independent nuclear regulatory body will be established by the end of 2018.[687]

Thailand

The National Energy Policy Council of Thailand in 2007 proposed that up to 5 GW of capacity be operational between 2020 and 2028. However, this target will not be met for a number of reasons, but significant among them is local opposition on the proposed sites. The latest proposal from the Electricity Generating Authority of Thailand (EGAT) is for two 1 GW units to be operational by 2036, although no location has been named.[688] Thailand's largest private power company has announced that it will invest US$200 million for a 10 percent stake of the China General Nuclear Power Corporation (CGN) and Guangxi Investment Group's Fangchenggang nuclear power plant in China.[689] CGN obviously eyes a role in the potential, although very vague, nuclear project in Thailand.

682 - *NIW*, "Saudi Arabia, Will Water Scarcity Spur Nuclear Growth?", 31 July 2015.

683 - *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.

684 - *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.

685 - *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.

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

687 - *NIW*, "Briefs—Saudi Arabia", 22 September 2017.

688 - *WNA*, "Emerging Nuclear Energy Countries", July 2018.

689 - *WNN*, "Thai power company buys into Fangchenggang II", 25 January 2018, see http://www.world-nuclear-news.org/NN-Thai-power-company-buys-into-Fangchenggang-II-2501164.html, accessed 25 April 2018.

Table 14 | Summary of Potential Nuclear Newcomer Countries

	Site	Proposed Vendor	Initial Startup Date	Proposed Construction Start	Current Startup Date
Under Construction					
Bangladesh	Rooppur	Rosatom	Nov 2017	April 2018	2023
Belarus	Ostrovets	Rosatom	2016/18		2019 (Q4)/2020 (Q3)
Turkey	Akkuyu	Rosatom	2015	2018	2023
UAE	Barakah	KEPCO	2017/18/19/20		2019/2020
Contract Signed or Advanced Development					
Lithuania	Visegrade	Hitachi	2020	Suspended	-
Turkey	Sinop	Mitsubishi/Areva		?	-
	Ingeada	SNPTC/Westinghouse		2019	-
Vietnam	Ninh Thuan	Rosatom	2020	Suspended	-
Committed Plans					
Egypt		Rosatom	2019	2018	2026/2027
Jordan		Rosatom		2019	2024
Poland				?	2029
Well Developed Plans					
Chile			2024	Suspended	-
Indonesia		Rosatom		Indefinitely Postponed	-
Kazakhstan		Rosatom or Westinghouse		?	-
Saudi Arabia			2020	?	2027
Thailand			2020-8	?	-

Sources: Various, compiled by WNISR, 2018

CONCLUSION ON POTENTIAL NEWCOMER COUNTRIES

The past twelve months have seen notable changes in the development of nuclear power in countries that have not operated it before, with both Bangladesh and Turkey starting construction on nuclear power plants for the first time. However, the experiences of other countries that are building nuclear power for the first time, are illustrated with further delays announced in United Arab Emirates, due to lack of suitably trained operators and the delayed Belarussian reactors startup still at least a year away.

Two other countries (Egypt and Saudi Arabia), both in the Middle East, appear to have made progress in the deployment of nuclear power but the next few years will determine whether this will result in the actual commencement of construction. See Table 14 for a general overview.

INTERDEPENDENCIES BETWEEN CIVIL AND MILITARY NUCLEAR INFRASTRUCTURES

Military interests as drivers for lifetime extension and new-build?

THE ODD PERSISTENCE OF NUCLEAR POWER

Why is it that nuclear power is proving surprisingly resistant in particular places around the world, to dramatically changing global energy market conditions and structures for electricity supply?[690] Against a backdrop of decline in the worldwide nuclear industry as a whole, plans for plant life-extension and nuclear new-build remain major areas of investment in a few specific countries. Intense attachments persist to projects like Hinkley Point C in the United Kingdom (U.K.), for instance, despite: a delay standing presently at more than a decade; costs multiplying fivefold over original estimates; a series of still-unresolved technical difficulties; and demands for escalating government financial concessions and guarantees.[691] Globally, successive issues of the WNISR show, how the relatively small number of continuing nuclear programs typically display a similar mix of severely deteriorating conditions and oddly dogged enthusiasm.

Although now increasingly replaced by the iconic status of other areas of innovation (like machine intelligence, synthetic biology, neuroscience and nanotechnology) one possible reason for the persistence of nuclear power in particular settings may relate to a residual effect of the past image of nuclear expertise as an epitome of scientific and technological prowess—and so a symbol of national standing.[692]

Yet it is surprising to see such persistent nuclear attachments, because nuclear energy has clearly become much less attractive, when compared with competing low-carbon options. Worldwide, nuclear is already significantly more expensive than major alternatives like solar photovoltaics (PV) and wind power—with the disadvantage growing fast (see also Nuclear Power vs. Renewable Energy Deployment).[693] Available cost-effective energy resources

690 - For an early picture of this dynamic, see for example: Lovins, Amory B., L. Hunter Lovins, and Leonard Ross, "Nuclear Power and Nuclear Bombs. Foreign Affairs", 1980 or Steve Thomas, "The realities of nuclear power : international economic and regulatory experience", Cambridge University Press, 1988. See also: Steve Thomas, "Competitive energy markets and nuclear power: Can we have both, do we want either?", *Energy Policy*, 15 May 2010, see http://www.provedor.nuca.ie.ufrj.br/eletrobras/estudos/thomas1.pdf, accessed 17 June 2018.

691 - Holly Watt, "Hinkley Point: The 'dreadful Deal' behind the World's Most Expensive Power Plant", *The Guardian*, 21 December 2017, see https://www.theguardian.com/news/2017/dec/21/hinkley-point-c-dreadful-deal-behind-worlds-most-expensive-power-plant, accessed 21 December 2017.

692 - See Gabrielle Hecht, "The Radiance of France: nuclear power and national identity after World War II", 2009, *MIT Press*. Some additional comparative implications across technologies around this point are addressed in Andy Stirling, "Towards innovation democracy? Participation, responsibility and precaution in the politics of science and technology", chapter in Annual Report of the Government Chief Scientific Adviser: see Government Office of Science, "Innovation: Managing Risk, Not Avoiding It—Evidence and Case Studies", 2014, see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381906/14-1190b-innovation-managing-risk-evidence.pdf, accessed 17 June 2018.

693 - In the U.K., for instance, this is recognized by numerous official analyses undertaken concurrently with the intense expressions of commitment to nuclear power cited above, e.g. NAO, "Nuclear Power in the UK", 13 July 2016 see https://www.nao.org.uk/wp-content/uploads/2016/07/Nuclear-power-in-the-UK.pdf, accessed 13 July 2016. Among (energy) economists, there is a general consensus that nuclear power has never been economical, and the detailed survey by Lucas W. Davis, "Prospects for Nuclear Power", *Journal of Economic Perspectives*, Vol.26, No.1, 49–66, 2012, see https://doi.org/10.1257/jep.26.1.49, accessed 13 July 2018.

from these renewables are huge,[694] and their modularity, small unit size and short lead times typically make them a more rapid means to carbon emissions abatement.[695] Where once nuclear advocates claimed that 'firm' (inflexibly-steady) nuclear output is an advantage, grid operators now recognize that new network technologies render the underlying idea of 'base load' power to be "*outdated*".[696] Many options exist to manage so-called intermittent power[697] at a fraction of the growing renewable cost advantage.[698]

Technologies with such strikingly cumulative comparative disadvantages as nuclear would be abandoned in most other sectors. Therefore, serious questions arise as to why the declared commitments of some governments should remain so oddly intense around a nuclear option that under-performs so obviously across so many energy policy criteria.

NEGLECTED MILITARY DIMENSIONS OF NUCLEAR POWER

Nuclear reactors, whether small or commercial-size, are the only effective means to produce crucial fissile materials for nuclear weapons, like plutonium-239. The fuel supply chain for nuclear power, and uranium enrichment in particular, is the source for high-enriched uranium, the other main strategic, weapons-usable fissile material. Further ingredients for various types of nuclear weapons, like tritium, are by-products of nuclear power. All these 'material links' have been acknowledged for many years and described in great detail. But less well appreciated in public debate, are a set of 'industrial interdependencies'—involving the wider nuclear skills, education, research, design, engineering and industrial capabilities associated with civil nuclear industries, that are also essential in many ways to the sustaining or introduction of nuclear weapons programs or their associated platforms and infrastructures.[699]

Together, these material links and industrial interdependencies are important for the world civil nuclear industry. For instance, most reactor design traditions derive from past prio-

694 - IRENA, "Renewable Power Generation Costs in 2017", International Renewable Energy Agency, January 2018.

695 - Ged Davis, José Goldemberg, eds. "Global Energy Assessment: Toward a Sustainable Future", Cambridge University Press, 2012.

696 - Karel Beckman, "Head of UK's National Grid Says 'idea of Large Power Stations for Baseload Is Outdated", *Energy Post*, 11 September 2015, see http://energypost.eu/interview-steve-holliday-ceo-national-grid-idea-large-power-stations-baseload-power-outdated/, accessed 11 September 2015.

697 - All power sources, including nuclear power, are to some extent subject to unanticipated fluctuations or interruptions in output. All are vulnerable to unplanned shutdowns, or need periodically to be withdrawn from service for maintenance, repair, refueling, or for other safety or security related reasons. The overall rate of availability of nuclear power plants ist about two thrids only, and unexpected outages are very considerable, see Stefan Seifert, et al., "Are Outages Homogeneous Among Nuclear Reactor Technologies? Evidence from Machine Learning Approaches", Working Paper, *DIW* Berlin, 2017.

698 - For instance the U.K. regulatory body Office of Gas and Electricity Markets (OFGEM) quotes the U.K. Energy Research Centre (UKERC) when stating in their own 2017 report that "at these levels, the UKERC estimates that integration costs are between £5 per MWh and £10 per MWh of intermittent energy (up to £478 million in 2016)", in OFGEM, "State of the Energy Market Report", 2017, see https://www.ofgem.gov.uk/system/files/docs/2017/10/state_of_the_market_report_2017_web_1.pdf, accessed 25 January 2018.

699 - John F. Schank, Jessie Riposo et al. "The United Kingdom's Submarine Industrial Base Volume 1: Sustaining Design and Production Resources", RAND Corporation, 2005, see https://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG326.1.pdf, accessed 18 June 2018.; and John F. Schank, Mark V. Arena et al "Sustaining US Nuclear Submarine Design Capabilities", RAND Corporation, 2007, see https://www.rand.org/content/dam/rand/pubs/monographs/2007/RAND_MG608.pdf, accessed 17 June 2018; see also NSSG, "Nuclear Skills Strategic Plan", Nuclear Skills Strategy Group, December 2016, see http://www.cogentskills.com/media/76258/national-nuclear-skills-strategic-plan.pdf, accessed 17 June 2018; and HM Government, "Sustaining Our Nuclear Skills— Nuclear Sector Skills Strategy: Government and Industry in partnership", 2015, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415427/Sustaining_Our_Nuclear_Skills_FINAL.PDF, accessed 17 June 2018.

ritization of military aims. Heavy water reactors and graphite-moderated designs like the Chernobyl-style RBMK or the French and U.K. natural uranium gas-graphite reactors were based on principles originally chosen to facilitate on-load refueling for production of plutonium required in nuclear weapons manufacture. Likewise, even the most modern variants of light water reactors are still built around basic engineering principles originally optimized for the confined spaces of nuclear-propelled submarines.[700] Yet, even after many decades of opportunities to establish entirely new designs dedicated to civilian power production, these military-derived variants still account for almost all of the global civil nuclear power capacity worldwide. In fact, there exists no major commercial reactor design, whose basic configuration was optimized from first principles solely for safe or economic civilian power. A high proportion of leading designs for a currently much-vaunted 'new generation' of Small Modular Reactors or SMRs (see the chapter on SMRs in WNISR2017) relate even more closely to contemporary nuclear submarine propulsion reactors.[701]

> *"perceived needs to maintain the naval nuclear propulsion industry is a major reason to continue with otherwise-declining civil nuclear power"*

Nor is there any sign that these longstanding connections are diminishing. An additional dimension to civil-military nuclear interdependencies has only come to light over recent years. This is the importance to government support of nuclear power in some countries of continuing commitments to build and maintain military, nuclear-propelled submarines.[702] These machines are often identified as being among the most complex and demanding manufactured artefacts ever conceived. Security concerns are seen to require the sustaining of the entire range of necessary industrial capacities within a single country. Only in the last couple of years, are inside sources beginning to acknowledge that (even in large economies like that of the U.S.), it is difficult to sustain this military capability without a parallel civil nuclear power industry.[703] High profile documents by industry bodies and senior policy figures openly urge that perceived needs to maintain the naval nuclear propulsion industry is a major reason to continue with otherwise-declining civil nuclear power.[704] National achievement of nuclear submarine capabilities is also widely associated with global strategic leadership, for instance with former President Dilma Rousseff of Brazil stating in 2014 on a visit to the new Brazilian nuclear

700 - Robin Cowan, "Nuclear Power Reactors: A Study in Technological Lock-In", *Journal of Economic History*, September 1990, see http://dimetic.dime-eu.org/dimetic_files/cowan1990.pdf, accessed 17 June 2018.

701 - WNA, "Small Nuclear Power Reactors", May 2018, see http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx, accessed 17 June 2018; and Oxford Economics Institute, "The economic benefit of improving the UK's nuclear supply chain capabilities", March 2013, see http://namrc.co.uk/wp-content/uploads/2013/04/economic-benefits.pdf, accessed 31 May 2016.

702 - The stealth, range, speed and endurance of nuclear-propelled ballistic missile submarines (SSBNs) has led them to become central to the strategic military doctrines of all five formally-recognized nuclear weapons states (U.S., Russia, U.K., France and China) as well as an unofficial nuclear weapons state, India. The necessity to maintain national nuclear submarine industries in business in between the 'drumbeat' of orders for these SSBNs, has helped lead all of these countries also to maintain in deployment a number of expensive nuclear-propelled fleet submarines (not armed with ballistic missiles). See Gavin Ireland, "Beyond Artful: Government and Industry Roles in Britain's Future Submarine Design, Build and Support", Royal United Services Institute, March 2007, see https://rusi.org/sites/default/files/200706_whr_beyond_artful.pdf, accessed 17 June 2018. Other major regional powers are also in various stages of acquiring nuclear submarine capabilities, including Iran, Brazil and Argentina.

703 - Energy Futures Initiative, "The US Nuclear Energy Enterprise: A Key National Security Enabler", August 2017, see https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5992f7e0bf629ad8f9d575ec/1502803938248/EFI+Nuclear+Report+FINAL+08.2017.pdf, accessed 24 June 2018.

704 - *E&E News*, "Addendum'—draft confidential memorandum with Attorney-Client Privilege", Leaked Document, 2018, see https://www.eenews.net/assets/2018/06/01/document_gw_01.pdf, accessed 17 June 2018.

submarine facility: "The Brazilian naval force... have contributed decisively to our nation, towards our country integrating into the select group of five member countries of the Council of the United Nations Security dominating the submarine construction technology with nuclear propulsion".[705]

There are, around the world, then, many major connections between civil and military nuclear industrial capabilities, skills, expertise and infrastructures. Furthermore, dependencies between civil and military nuclear are often greater than between nuclear-specific engineering and other industrial sectors.

Thus, if civilian nuclear power and its associated specialist practices are to be allowed (like many earlier technologies) to go obsolete, then the nuclear establishments of a small number of countries that maintain *military* nuclear ambitions that would disproportionately be the losers. Conversely, for those hoping for long-stalled reversal in either horizontal or vertical nuclear weapons proliferation[706], it is possible that obsolescence of civil nuclear power as an energy source forms a potentially major global opportunity.

BROAD PATTERNS IN NATIONAL CIVIL AND MILITARY NUCLEAR AMBITIONS

In all states with current and past nuclear weapons capabilities, parallel availability of the skills and industrial and research capacities now associated with civil nuclear power have been essential.[707] The revenues arising from nuclear electricity sales have also been important, as part of these flow indirectly into supply chains and research, training and industrial systems that have joint civil and military applications.[708] Some states (notably Israel and North Korea) have built modest military nuclear capabilities without directly pursuing civil nuclear power. But even here, existence of wider international nuclear industries (especially in sponsoring powers) has remained crucial.[709]

705 - Defesa Aérea & Naval, "Com a presença da Presidente, Marinha do Brasil inaugura prédio principal do Estaleiro de Construção de Submarinos", 2014, (in Portuguese), see http://www.defesaaereanaval.com.br/com-a-presenca-da-presidente-marinha-do-brasil-inaugura-predio-principal-do-estaleiro-de-construcao-de-submarinos/, accessed 17 June 2018.

706 - Horizontal proliferation is the spread of nuclear weapons, materials, facilities or knowledge to countries that have not yet developed nuclear weapons. Vertical proliferation can be defined as increasing the nuclear weapon stockpiles or capabilities in a state that is already possessing nuclear weapons.

707 - This is true, for instance, of the nuclear weapons and military nuclear propulsion capabilities of all the major nuclear-armed states: China, France, Russia, the U.K. and the U.S. In the very first stages of the global nuclear industry, the extraordinary circumstances of World War II and the early Cold War led to huge industrial efforts dedicated to military aims. But with rapid deployment of the first nuclear power reactors, infrastructures for uranium enrichment and spent fuel reprocessing quickly became shared between civil and military industries (economists have called this phenomenon "economics of scope", see Christian von Hirschhausen, "Nuclear Power in the Twenty-First Century: An Assessment (Part I)", Discussion Paper, *DIW*, Berlin, 2017. In countries developing military weapons capabilities at a later stage, like India and Pakistan, active development of a shared civil-military national base in general nuclear skills and expertise featured even more strongly. Although in the latter case of Pakistan, an operating national civil nuclear program has not yet eventuated, strategic reliance is significant on just such a program in China.

708 - This interlinkage has been clearly demonstrated in a very direct sense, for instance, in the U.K., where reactor designs were adopted for civilian electricity production that also facilitated production of fissile plutonium for military purposes and were operated this way by civilian utilities for many years, with plutonium diverted to weapons use, cf. David Lowry, "Military secrets of our nuclear power plants", *The Guardian*, 27 December 2017, see https://www.theguardian.com/uk-news/2017/dec/27/military-secrets-of-our-nuclear-power-plants, accessed 14 August 2018. The earliest civilian reactors adopted in France were of a similar design.

709 - This is the case in a strict sense, only in North Korea and Israel. But the very close relationships of each of these countries with powerful nuclear-armed patrons (with an active civil nuclear infrastructure – in China and France and the U.S. respectively) shows how international joint civil-military infrastructures remain essential.

Countries like Canada, Germany, Sweden and Switzerland were all enthusiastic pioneers of civil nuclear power, who also entertained early nuclear military ambitions, but which each later relinquished nuclear weapons. And these linkages can also be found in the history of ostensibly civilian nuclear programs of currently non-nuclear weapons states including Argentina, Bangladesh, Brazil, Japan, South Africa and South Korea. Likewise, such links are well acknowledged in contemporary politics around the projected nuclear programs of Egypt, Saudi Arabia, Turkey and the United Arab Emirates. The *Economist* for instance, argues of Saudi Arabia's potential nuclear new-build program, that it makes "little economic sense".[710] The Saudi King has put this directly into a military context, in stating that "without a doubt, if Iran developed a nuclear bomb, we will follow suit as soon as possible".[711] Civil nuclear programs in Egypt, Turkey and the United Arab Emirates, are held to be among the countries "most poised to seek advanced nuclear capabilities in response to a resurgent nuclear Iran".[712]

"if Iran developed a nuclear bomb, we will follow suit as soon as possible"

One rough circumstantial reflection of these evident general civil-military nuclear connections can be seen in the coarse-grain structure of resonating nuclear and military enthusiasms around the world today. Figure 32 below illuminates broad overlapping patterns across all relevant countries, between general military standing, nuclear weapons status, nuclear submarine capabilities, global geopolitical profile and the intensity of declared civil nuclear ambitions (as expressed in data published by the leading nuclear industrial advocacy organization).

According to the positions asserted in national data published by the World Nuclear Association (WNA), the five largest-scale prospective nuclear new-build programs in the world are in four of the five 'official' nuclear weapons states (excepting France).[713] India is also pursuing an ambitious nuclear new-build program. And France is an illuminating exception, in that the scale of its existing reliance on nuclear power in itself militates against further large-scale national expansion. So large is the existing French civil nuclear fleet, that the associated national engineering base also required for military purposes, is much less under threat from nuclear decline than in other countries. But the *Le Monde* newspaper nonetheless does still highlight "the ultimate question an expert dares asking": "What would become of the credibility of our nuclear weapons program and our position at the UN [Security Council], if France were to renounce its [nuclear power] plants?"[714]

710 - *The Economist*, "How a Saudi Nuclear Reactor Could Accelerate an Arms Race", 8 February 2018, see https://www.economist.com/middle-east-and-africa/2018/02/08/how-a-saudi-nuclear-reactor-could-accelerate-an-arms-race, accessed 5 May 2018.

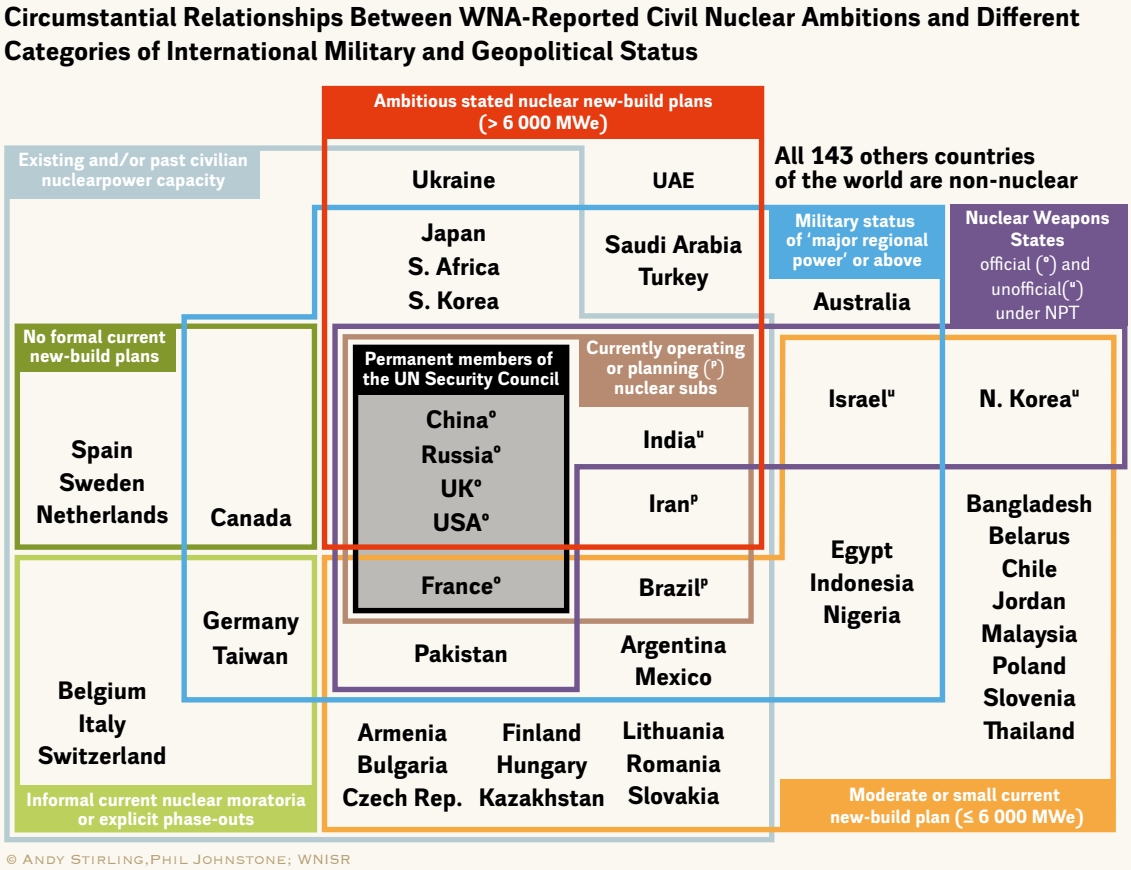
711 - *CBS News*, "Saudi Crown Price: If Iran develops nuclear bomb, so will we", *15 March 2018, see* https://www.cbsnews.com/news/saudi-crown-prince-mohammed-bin-salman-iran-nuclear-bomb-saudi-arabia/, accessed 17 June 2018.

712 - Sarah Burkard, Erica Wenig et al, "Nuclear Infrastructure and Proliferation Risks of the United Arab Emirates, Turkey, and Egypt", Institute for Science and International Security, 25 August 2017, see http://isis-online.org/isis-reports/detail/nuclear-infrastructure-and-proliferation-risks-of-the-united-arab-emirates/, accessed 17 June 2018.

713 - The five largest declared nuclear new-build programs published by the WNA in 2017 were as follows: China 233 GWe; Russia 53 GWe; India 47.9 GWe; U.S. 33.1 GWe; U.K. 17.9 GWe, corresponding to five of the world's six major nuclear weapons powers. WNA, "Nuclear Power in the World Today", April 2018, see http://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx, accessed 27 July 2018.

714 - Jean-Michel Bezat, "Nucléaire: Pourquoi La France Persiste", *Le Monde*, 28 July 2017, (in French), see https://prepaecocarnot.files.wordpress.com/2017/08/nucleaire_en_france_le_monde_juillet_2017.pdf, accessed 19 August 2018.

Figure 32 | Circumstantial Relationships Between Reported Civil Nuclear Ambitions and Different Categories of International Military and Geopolitical Status (civil nuclear plans are based on WNA data)[715]



Source: Andy Stirling, Phil Johnstone, WNISR 2018

The major state-held Russian nuclear construction and services company Rosatom is clear that the "[r]eliable provision of Russia's defense capability is the main priority of the nuclear industry".[716] And in the U.S., the Nuclear Energy Institute, now strongly lobbies for subsidies for failing nuclear developments, on the grounds that abandonment of these will "stunt development of the nation's defense nuclear complex".[717] Likewise, the pro-nuclear *Environmental Progress* group, highlights the national security implications of the U.S.A's declining nuclear industry.[718] Perhaps most significantly, former U.S. Energy Secretary Ernest Moniz, argued in

715 - Since the object of interest here are 'declared nuclear ambitions', rather than 'realistically deliverable plans', WNA is the appropriate source. Data for formally stated nuclear ambitions are from WNA, "Nuclear Power in the World Today—2018", June 2018, see http://www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requireme.aspx, accessed 28 June 2018. The allocations of countries to categories in this picture are based entirely on this WNA data with no modifications to reflect alternative views. Where a detailed WNA country report conflicts with the summary table, it is the more detailed data that is used here. Data for regional military power status are from Detlef Nolte, "How to compare regional powers: analytical concepts and research topics", Review of International Studies, October 2010, see https://www.giga-hamburg.de/sites/default/files/publications/how_to_compare.pdf, accessed 17 June 2018.

716 - Rosatom, "Росатом Полностью Выполнил Государственный Оборонный Заказ 2017 Года," 25 December 2017, (in Russian), see https://ria.ru/defense_safety/20171225/1511650489.html?inj=1, accessed 25 January 2018.

717 - Amy Harder, "Nuclear scramble on tax credits", *Axios News Service*, 16 June 2017, see https://www.axios.com/nuclear-scramble-on-tax-credits-1513303038-7c4178f7-f93a-4614-bb13-efbca70c4835.html, accessed 27 July 2018.

718 - Michael Shellenberger, "Nuclear Industry Must Change — Or Die", *Environmental Progress Website*, 17 February 2017, see http://environmentalprogress.org/big-news/2017/2/16/nuclear-must-change-or-die, accessed 12 March 2018.

2011 already in favor[719], and launched a report in 2017, which stated that "a strong domestic supply chain is needed to provide for nuclear Navy requirements. This supply chain has an inherent and very strong overlap with the commercial nuclear energy".[720] Accordingly, a memorandum leaked under the Trump administration in June 2018, reveals that recent regulatory measures to protect nuclear power reflect high-level perceptions that the civil nuclear industry is essential to national security, specifically including naval propulsion.[721] Incidentally, the same month of June 2018, "several dozen retired generals and admirals, former State, Defense and Energy Department officials, three former chairmen of the Nuclear Regulatory Commission, and a sprinkling of former senators, governors, industrialists and other worthies"[722] wrote a letter to U.S. Energy Secretary Rick Perry[723], to commend him "for recognizing the important role our civil nuclear energy sector plays in bolstering America's national security" and to urge him "to continue to take concrete steps to ensure the national security attributes of U.S. nuclear power plants are properly recognized by policymakers and are valued in U.S. electricity markets". The authors also state that "the national security benefits of a strong domestic nuclear energy sector take many forms, many of which overlap and together are woven into the nation's greater strength and resilience". As example they are citing:

> Several national security organizations, including our nuclear Navy and significant parts of the Department of Energy [DOE], benefit from a strong civil nuclear sector. Many of the companies that serve the civil nuclear sector also supply the nuclear Navy and major DOE programs.

In a stinging comment on the Perry letter, Victor Gilinsky and Henry Sokolski, respectively former Commissioner of the Nuclear Regulatory Commission (NRC) and Executive Director of the Nonproliferation Policy Education Center, write:

> For years, the nuclear industry insisted that civilian nuclear power had nothing to do with weapons programs. That was then. Now, in a desperate attempt to keep no-longer-competitive nuclear plants from being shuttered, the industry claims there really has been a connection all along, and electricity customers should pay a premium to keep it going. It is one claim too many. (...)
>
> The whole point of the body of the Perry letter is that there is a close connection between U.S. nuclear power and our nuclear weapons programs. Why should we think that this connection is not present in other countries?[724]

719 - See Ernest Moniz, "Why We Still Need Nuclear Power", *Foreign Affairs*, 2011.

720 - Energy Futures Initiative, "The US Nuclear Energy Enterprise: A Key National Security Enabler", 2017, see https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5992f7e0bf629ad8f9d575ec/1502803938248/EFI+Nuclear+Report+FINAL+08.2017.pdf, accessed 19 August 2018. This report is associated with former U.S. Energy Secretary Ernest Moniz, for instance by the industry and financial news agency *Bloomberg*: Ari Natter, "Nuclear Power's Woes Imperil U.S. National Security, Moniz Says", *Bloomberg*, 15 August 2017, see https://www.bloomberg.com/news/articles/2017-08-15/nuclear-power-s-woes-imperil-u-s-national-security-moniz-says, accessed 20 August 2017.

721 - *E&E News*, "'Addendum'—Leaked draft confidential memorandum with Attorney-Client Privilege]", Leaked Document, 2018, see https://www.eenews.net/assets/2018/06/01/document_gw_01.pdf, accessed 17 June 18.

722 - Victor Gilinsky, Henry Sokolski, "The 'Threat' of Nuclear Power Plant Closures", *The National Interest*, 8 August 2018, see https://nationalinterest.org/feature/threat-nuclear-power-plant-closures-28262, accessed 17 August 2018.

723 - Quotes hereunder from joint letter to U.S. Energy Secretary Rick Perry, dated 26 June 2018, see https://www.nei.org/CorporateSite/media/filefolder/resources/letters-filings-comments/letter-secretary-energy-rick-perry-nuclear-national-security-20180626.pdf, accessed 17 August 2018.

724 - Victor Gilinsky, Henry Sokolski, op.cit.

Evident in Figure 32 is a pattern under which, of the relatively few other countries in the world presenting themselves as pursuing the most ambitious civil nuclear new-build plans, eleven out of thirteen hold the status of being major (at least regional) military powers.[725] With regard to the next tier of stated national ambitions for nuclear power, an association between civil nuclear and military interests is also apparent. Of 23 countries widely designated as 'major regional powers' or above, only Australia has never developed, or is not seeking to develop, a civil nuclear program. And among those in this group who have developed such programs in the past, only Germany and Taiwan are presented by the WNA to be without any nuclear new-build programs.

> *"having nuclear power means that we can manufacture nuclear weapons within a certain period of time"*

Given the complexities of global affairs, it must be expected that any general pattern like this will include exceptions. That the United Arab Emirates (UAE) is the only example in the world of a country displaying high stated civil nuclear ambitions that is not at least a regional military power, is actually an indication of the striking nature of the broader patterns shown in Figure 31. And it is notable in this regard, that the UAE is also at the geographical center of what is currently one of the most intense areas of regional military tension—and whose stated ambitious nuclear plans are in any case somewhat performative. Likewise, North Korea is already a nuclear-armed state, which is not formally categorized as a regional military power. But this involves other well-known extraordinary circumstances, implicating arguably the single most acute military nuclear stand-off in the contemporary world. On the other hand, Germany is the only regional military power, which WNA acknowledges to be actively scaling back its civil nuclear programs. This is also a special case, in that the '*Energiewende*' policy in Germany has been forced by globally distinctive social mobilization.[726] In Japan, the current reigning back of plans for nuclear power conditioned by the even more unique political consequences of the Fukushima catastrophe, is not reflected in WNA projections.[727] And here, civil-military links are evidently salient, for instance, in senior Liberal Democrat politician Shigeru Ishiba's statement that "Japan should never let go of nuclear power plants. Because having nuclear power means that we can manufacture nuclear weapons within a certain period of time and it can be a deterrent".[728]

725 - The exception is the Ukraine, a case which is also made exceptional by a situation of armed proxy conflict with the powerful nuclear-armed neighbor Russia. In other cases, active tension with already nuclear-armed antagonists is also often a factor. This is true of India (which also maintains nuclear submarine capabilities). Abhijit Singh, "Why India Needs Both Nuclear and Conventional Submarines", *The Diplomat*, 7 May 2016, see http://thediplomat.com/2016/05/why-india-needs-both-nuclear-and-conventional-submarines/, accessed 17 June 2018;

726 - Craig Morris, Arne Jungjohann, "Energy democracy: Germany's Energiewende to renewables", Palgrave, 2016.

727 - And in any case, both Germany and Japan are countries, where ostensibly civil nuclear infrastructures were developed in highly uneconomic ways that historically brought national infrastructures to the brink of weapons production capability in a context of threat by major nuclear-armed neighbors. Indeed, it has been noted, how this need for a civil industry as a base for military power is still being asserted in Japan. The only other remaining exception at this lower level of the pattern in Figure 32 is Taiwan, which is a regional military power with no civil nuclear new-build plans. But, like Germany and Japan, Taiwan also has a strong history of nuclear commitment in the past.

728 - Quoted in Asyura2, "半歩前へ, "核兵器製造技術は「抑止力につながる」と石破茂！", 18 November 2017, (in Japanese), see http://www.asyura2.com/17/senkyo235/msg/873.html, accessed 10 May 2018.

THE CASE OF THE U.K.

The U.K. was one of the first developers of both nuclear weapons and commercial nuclear power. With early civil nuclear facilities documented to have been central to military plutonium production[729], joint civil-military nuclear ambitions are especially relevant in the U.K. Military nuclear standing is frequently emphasized as being central to elite British political identities on the world stage:[730] suggestive of the cherished status of a country that "punches above its weight";[731] and indirectly linked to the "seat at the top table" of permanent membership of the UN Security Council.[732]

So, it is no surprise that the U.K. should currently be pursuing declared nuclear new-build commitments that are exceptional in Europe (and in proportion to its system, the largest in the world); and with the then-responsible minister insisting in 2016 that "nuclear power is what this Government is all about for the next twenty years".[733]

It is long since the U.K. undertook any kind of full policy analysis systematically to justify its nuclear commitments. The U.K. Parliament's National Audit Office (NAO) departed from normal procedure by explicitly criticizing in 2017 that Government, in its review of the proposed Hinkley Point C project, "has not formally reviewed and consulted on its published strategic case for nuclear power since the publication of the 2008 white paper".[734] And, in addition, this last attempt to justify the current nuclear program, was itself based on a consultation process that was successfully challenged by judicial review for being too cursory.[735]

Thus, the most recent major U.K. energy policy initiative that was not subject to this kind of general formal skepticism goes back even further, to 2003. And, based on a far more comprehensive analysis, the conclusion of this last fully-considered U.K. Government energy white paper was that nuclear power is "unattractive".[736] Openly unwelcome to the then Prime Minister Tony Blair[737], it was this finding that was over-ridden by the cursory white paper of 2008 in

729 - As discussed in Lorna Arnold, "Britain and the H-Bomb", Palgrave, 2001.

730 - Tim Ross, "Former Labour defence chief George Robertson warns Jeremy Corbyn not to scrap Trident", *The Telegraph*, 13 February 2016, see https://www.telegraph.co.uk/news/uknews/defence/12155420/Former-Labour-defence-chief-George-Robertson-warns-Jeremy-Corbyn-not-to-scrap-Trident.html, accessed 17 June 2018.

731 - Patrick Cockburn, "Why Must Britain Always Try to 'Punch above Her Weight'?", *The Independent*, 17 July 2011, see http://www.independent.co.uk/voices/commentators/patrick-cockburn-why-must-britain-always-try-to-punch-above-her-weight-2314908.html, accessed 17 June 2018.

732 - Patrick Barckham, Richard Norton-Taylor, "Trident: Deadly – and Very, Very Expensive", *The Guardian*, 20 May 2010, see https://www.theguardian.com/uk/2010/may/20/trident-submarine-coalition-government-scrap, accessed 17 June 2018.

733 - *BBC Radio 4*, "The Today Programme: Interview with Amber Rudd", *23 March 2016, see* https://www.youtube.com/watch?v=_tsBkVjRllg, accessed 17 June 2018.

734 - NAO, "Hinkley C", National Audit Office, *23 June 2017, see* https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-C.pdf, accessed 23 June 2017.

735 - High Court judge Jeremy Sullivan described the Government's nuclear consultation at this time as "flawed", "misleading" and "procedurally unfair"; see *BBC News*, "Nuclear review 'was misleading'", 15 February 2007, see http://news.bbc.co.uk/1/hi/uk_politics/6364281.stm, accessed 17 June 2018.

736 - As stated on page 44 of the DTI White Paper, "Although nuclear power produces no carbon dioxide, its current economics make new nuclear build an unattractive option and there are important issues of nuclear waste to be resolved. Against this background, we conclude it is right to concentrate our efforts on energy efficiency and renewables"; *see* DTI, "Our Energy Future: Creating a Low Carbon Economy" Department of Trade & Industry, February 2003, see http://webarchive.nationalarchives.gov.uk/+/www.berr.gov.uk/files/file10719.pdf, accessed 17 June 2018.

737 - Matthew Tempest, "Blair accused of energy 'greenwash'", *The Guardian*, 24 February 2003, see https://www.theguardian.com/environment/2003/feb/24/energy.greenpolitics, accessed 17 June 2018.

a process acknowledged by Parliamentarians[738] and nuclear proponents [739] alike, to have been extraordinarily secretive.

A question that arises unusually explicitly and specifically in the U.K. case, then, is what these powerful "strategic factors" might be, that have so emphatically trumped stated energy policy considerations?

Again, the NAO cast some light on this, observing in their 2008 report on the U.K. Trident nuclear weapons program that "[o]ne assumption of the future deterrent programme is that the United Kingdom submarine industry will be sustainable and that the costs of supporting it will not fall directly on the future deterrent programme".[740]

There is one explanation that is notably consistent with both NAO's 2008 Trident and 2017 Hinkley Point reports. This is, that the oddly-unspecified "unquantified strategic benefits" that the NAO observed in 2017 to be driving U.K. Government support for otherwise uneconomic civil nuclear power, relates directly to the military nuclear submarine capabilities that they assumed in 2008 to be underwritten from other sources.[741]

These official statements by the U.K.'s leading public audit body confirm a picture that is highly visible in defense debates, but remarkably undiscussed in energy policy. With heavily redacted documents released under freedom of information legislation expressing strong anxieties[742], a host of other defense policy discussions clearly state that the U.K. nuclear 'submarine industrial base' would not be sustainable, if a decision were taken to discontinue civil nuclear power.[743] Statements from U.K. submarine industry sources note incentives to "mask" the costs of this military program behind the related civilian industrial infrastructure.[744] Submarine reactor manufacturer Rolls Royce recently dedicated a major report in large part to the argument that a program of submarine-derived small modular reactors should be adopted in U.K. energy poli-

738 - The U.K. Parliamentary Environmental Audit Committee outlined that "the Government has failed to clarify the nature of the review" and that "(...) that the process by which it is being conducted appears far less structured and transparent than the process by which the [20013] White Paper itself was reached.". See Environmental Audit Committee, "Keeping the lights on: nuclear, renewables, and climate change—Sixth Report of Session 2005-06", Volume I, House of Commons, 28 March 2006, see https://publications.parliament.uk/pa/cm200506/cmselect/cmenvaud/584/584i.pdf, accessed 17 June 2018.

739 - Nuclear advocate Simon Taylor notes the "secrecy" in which the second energy review took place "behind closed doors", with a secret working group within Tony Blair's cabinet office, which many in the cabinet office itself were not aware of; Simon Taylor, "The fall and rise of nuclear power in Britain", UIT Cambridge, 2016.

740 - See section 5.3 page 7; Tim Burr, "The United Kingdom's Future Nuclear Deterrent Capability", Comptroler and Auditor General, NAO, Ministry of Defence, 5 November 2008, see https://www.nao.org.uk/wp-content/uploads/2008/11/07081115.pdf, accessed 17 June 2018.

741 - These "unquantified strategic benefits" are acknowledged in the 2017 NAO report on Hinkley Point C to extend beyond the officially-stated "energy trilemma" around affordability, climate change and energy security. Yet neither here nor anywhere else do the NAO or any other government body anywhere disclose what these other "unquantified strategic benefits" actually are. Andy Stirling, Phil Johnstone, "Some Queries over Neglected Strategic Factors in Public Accounting for U.K. Nuclear Power: evidence to the House of Commons Public Accounts Committee Inquiry on Hinkley Point C", Science Policy Research Unit, University of Sussex, 25 September 2017, see http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/public-accounts-committee/hinkley-point-c/written/70983.pdf, accessed 17 June 2018.

742 - Robin Grimes et al, "Royal Navy Nuclear Reactor Test Facility Review", Ministry of Defence, 28 October 2014, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/658328/2016-03111.pdf, accessed 17 June 2018.

743 - Defence Committee, "The Future of the UK's Strategic Nuclear Deterrent : the strategic context", Eighth Report of Session 2005-06, House of Commons, 30 June 2006, see https://publications.parliament.uk/pa/cm200506/cmselect/cmdfence/986/986.pdf, accessed 17 June 2018.

744 - Gavin Ireland, "Beyond Artful: Government and Industry Roles in Britain's Future Submarine Design, Build and Support", Whitehall Report 3-07, The Royal United Services Institute for Defence and Security Studies, March 2007, see https://rusi.org/sites/default/files/200706_whr_beyond_artful.pdf, accessed 17 June 2018.

cy in order to "relieve the Ministry of Defence of the burden of developing and retaining skills and capability" on the military side.[745]

> *"seek a recognisable career pathway between the civil and defence sectors to ease transfer between the two"*

These civil-military links are also highly visible in U.K. industrial strategy, with priority given to a nuclear 'sector deal' spanning both sectors together and with many new agencies and programs openly dedicated to achieving synergies between U.K. submarine and civil nuclear programs. The nuclear sector deal is particularly focused on facilitating 'mobility' between the civil and defense nuclear workforce as a key strategy to manage the skills challenge. It is stated in "The Nuclear Sector Deal"[746] that "the sector is committed to increasing the opportunities for transferability between civil and defense industries and generally increasing mobility to ensure resources are positioned at required locations" and that 18 percent of projected skills gaps can be met by 'transferability and mobility'. The document also states that the skills gap can be met through "greater alignment of the civil and defense sectors with increased proactive two-way transfer of people and knowledge. As the military service sector tends to be age and nationality limited, we propose that we actively seek a recognisable career pathway between the civil and defence sectors to ease transfer between the two".

The Nuclear Skills Strategic Plan" outlines: "Demand for competent people is forecast to rise from 78,000 full time equivalent people (FTEs) in 2015 to 111,000 by 2021, requiring a total industry inflow of 9,000 per year" which includes both civil and defense activities. Precise numbers on defense requirements are not given in latest skills documentation and important caveats are required. One is that it is acknowledged that "in the civil sector, the new-build programme means that the main challenge is in the 'generic skills' element. For defence, and research and development, the challenge is more located in the area of subject matter experts". While generic skills are not specific to nuclear, the defense industry has more requirement for nuclear-specific skills in the long term. Also the analysis of future skills "averages across the industry and will not reflect movement within the industry".[747]

This recent emphasis on mobility came after earlier statements on the severe crisis in the nuclear submarine industry. As stated by Grimes et al: "Across the enterprise the availability of deep specialist expertise in key and suitably qualified staff appears to be at the bare minimum necessary to deliver the programme".[748] There are additional pressures on the defense nuclear

745 - Rolls Royce, "UK SMR : A National Endeavour", 2007, see https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/nuclear/a-national-endeavour.pdf, accessed 17 June 2018.

746 - NIC, "The Nuclear Sector Deal—Nuclear Industry Council Proposals to Government for a Sector Deal", Nuclear Industry Council, 7 December 2017, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/665473/The_Nuclear_Sector_Deal_171206.pdf, accessed 7 December 2017.

747 - NSSG, "Nuclear Skills Strategic Plan", Nuclear Skills Strategy Group, December 2016, see http://www.cogentskills.com/media/76258/national-nuclear-skills-strategic-plan.pdf, accessed 17 June 2018. Earlier reports highlight specific future requirements of both civil and defense. In the Nuclear Energy Skills Alliance "Workforce Assessment" in 2014, it is outlined that the annual forecast required recruitment per year for defense as being 1,090 up until 2021. This report also provides figures on the numbers employed in civil and defense: "Operations (including generation), decommissioning and fuel processing directly employs around 20,000 workers at some 30 sites across the U.K. Around half of those are based at Sellafield... Defence employs a further 20,000 with around 4,500 within the Royal Navy." See NESA, "Nuclear Workforce Assessment 2014", Nuclear Energy Skills Alliance, Nuclear Industrial Partnership, 2014, see http://130.88.20.21/uknuclear/pdfs/NESA_Nuclear_Workforce_Assessment_2014.pdf, accessed 17 June 2018.

748 - Robin Grimes et al, op.cit.

program as most workers have to be British nationals for security reasons and for cuts MoD budgets contribute to pressures on the submarine industry.[749]

These included acknowledgements of overlaps and shared skills between defense and civil and the benefits of civil engagement for defense, as illustrated by Rolls Royce: "Skills are considered to be transferable between military propulsion and civil programmes", where "a larger involvement in the broader [civil] industry will also have a spillover benefit to military capability through skill development and experience exchange[750] as well as admissions that the decline of civil nuclear has exacerbated skills challenges related to defense.

As acknowledged by the Keep Our Future Afloat campaign (KOFAC), "the decline of the UK civil nuclear programme has forced the military nuclear programme, and in particular the nuclear submarine programme, to develop and fund its own expertise and personnel in order to remain operational".[751] Additionally, in terms of Research & Development (R&D) support, it has been noted that "the MOD's [Ministry of Defence] programme had been underwritten by civil nuclear research that has over the years been dismantled and commercialised", where the "(...) expertise these activities generated has atrophied".[752]

Grimes et al, are providing specific recommendations for managing the capabilities crisis in the nuclear submarine industry through further engagement with the civil sector. This includes that "the programme seek imaginative methods to better engage with the emergent civil new-build programme on nuclear matters to the benefit of Defence", that "the Research Programme Group establish a workstrand to look at leveraging to maximum effect civil nuclear investment", and that "MOD revisit the possible option of utilising other nuclear facilities including those in the civil sector".[753]

Stephen Lovegrove, current Permanent Secretary at the Ministry of Defense and former Permanent Secretary at the Department for Energy and Climate Change responsible for negotiating the Hinkley Point C contracts, stated under questioning by the U.K. Parliament Public Accounts Committee[754]: "We are completing the build of the nuclear submarines, which carry conventional weaponry. We have at some point to renew the warheads, so there is very definitely an opportunity here for the nation to grasp in terms of building up its nuclear skills. I do not think that that is going to happen by accident; it is going to require concerted Government action to make it happen."[755]

749 - Robin Grimes et al, op.cit.

750 - Rolls Royce in The Innovation, Universities, Science and Skills Committee, "Engineering the future: turning ideas into reality—Volume II", Fourth Report of Session2008-09, House of Commons, 18 March 2009, see https://publications.parliament.uk/pa/cm200809/cmselect/cmdius/50/50ii.pdf, accessed 17 June 2018.

751 - KOFAC in EV109 of North West Regional Committee, "The Future of the Nuclear Industry in the North West—oral and written evidence", House of Commons, 9 March 2010, see https://publications.parliament.uk/pa/cm200910/cmselect/cmnwest/361/361.pdf, accessed 17 June 2018.

752 - Robin Grimes et al, op.cit.

753 - Robin Grimes et al, op.cit.

754 - The statement was issued in response to a submission by Andy Stirling, Phil Johnstone, " Some Queries over Neglected Strategic Factors in Public Accounting for U.K. Nuclear Power: evidence to the House of Commons Public Accounts Committee Inquiry on Hinkley Point C", 25 September 2017, see http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/public-accounts-committee/hinkley-point-c/written/70983.pdf, accessed 17 June 2018.

755 - Stephen Lovegrove, in Public Accounts Committee, "Oral Evidence: Hinkley Point C, HC 393", House of Commons, 9 October 2017, see http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/public-accounts-committee/hinkley-point-c/oral/71001.pdf, accessed 18 June 2018.

It is these remarkable conjunctions that have helped lead to reports in the U.K.[756] and international[757] press, that what is underway in the U.K. is, in effect, an unacknowledged cross-subsidy (perhaps amounting to several tens of billions of pounds)[758] away from electricity consumers and to the benefit of military nuclear interests. Whatever the actual figures may prove to be amidst many complexities and uncertainties, the *prima facie* evidence seems clear that future U.K. electricity prices are being raised significantly higher than would otherwise be the case, at least partly in order indirectly to support military nuclear infrastructures by enabling a flow of resources into joint civil-military nuclear engineering supply chains and wider shared provisions for nuclear skills, research, design and regulation.

The attraction of this strategy for the U.K. Government appears to lie in the triple aim of: (1) finding a means to cover the otherwise insupportable costs of this major military commitment; (2) whilst keeping the resulting expenditures away from inconvenient public scrutiny; and (3) entirely off the public books. But what is perhaps most remarkable, is that these evidently powerful pressures with apparently major impacts, remain entirely undiscussed anywhere in U.K. energy policy or related media debates.

NUCLEAR POWER, NUCLEAR WEAPONS AND DEMOCRACY[759]

Nuclear power is a controversial and expensive technology with a number of adverse wider characteristics, that is increasingly recognized to be growing obsolete by comparison with competing low-carbon energy technologies, yet which continues to receive intense continuing strong government support in several places around the world. The reasons for this are seriously under-documented and under-scrutinized in energy policy arenas. Given the volume, depth and ostensible rigor of detailed energy analysis around the world, this substantive gap in discussion is remarkable.[760]

756 - *The Guardian*, "Electricity consumers 'to fund nuclear weapons through Hinkley Point C'", 12 October 2017, see https://www.theguardian.com/uk-news/2017/oct/12/electricity-consumers-to-fund-nuclear-weapons-through-hinkley-point-c, accessed 12 October 2017.

757 - Eg: Peter Wynn-Kirby, "Britain's nuclear coverup", *The New York Times, 10 October 2016, see* https://www.nytimes.com/2016/10/11/opinion/britains-nuclear-cover-up.html?mcubz=3, accessed 18 June 2018. Also; Ralph Sotscheck, "Britisches AKW Hinkley Point C: Hidden Money für Atom-U-Boote", *Die Tageszeitung Online, 23 November 2016; see* http://www.taz.de/!5356383/, accessed 18 June 2018.

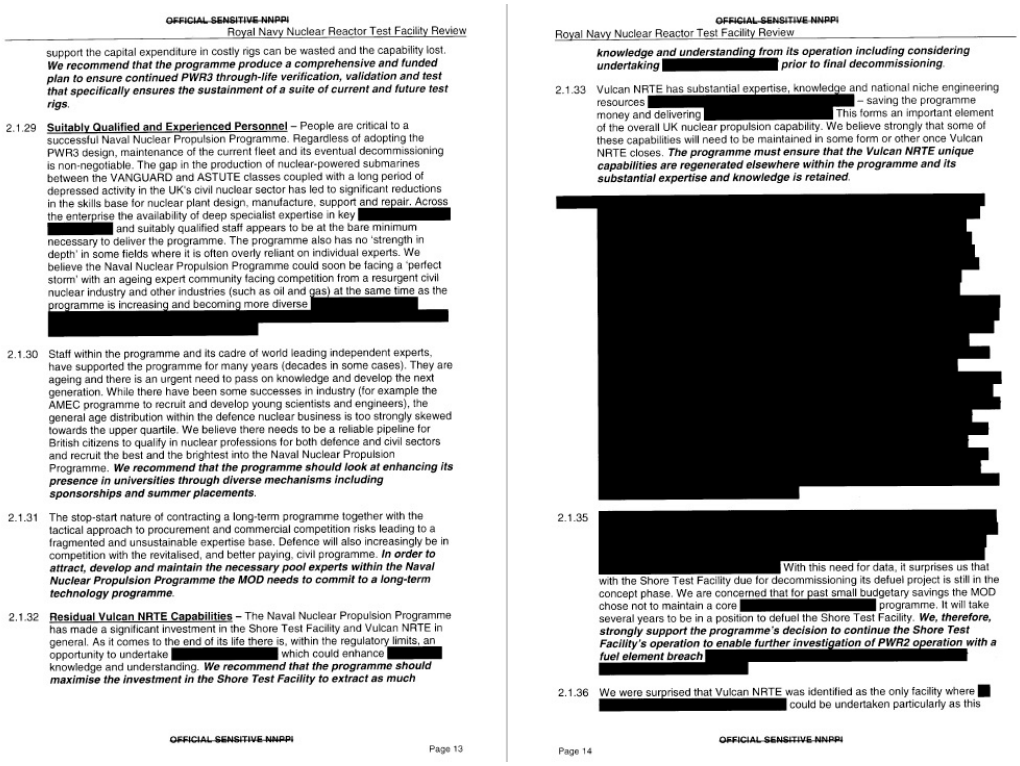
758 - Offshore wind power was being contracted for in the U.K. in 2017 at 55 £/MWh, against the backdrop of a long-run steady decline in costs. Power from Hinkley Point C, by comparison, is awarded Government-guaranteed contracts over 35 years from planned completion of the plant in the mid 2020s at a value set (in comparable 2017 prices) at 102.5 £/MWh (against a worldwide backdrop of steady increase in nuclear costs). Even if it is assumed (in a way that is highly unfavourable to wind power) that this currently-accelerating renewable cost advantage remains unchanged from 2017 not only until completion of Hinkley Point C, but also (even more unfavourably to wind) throughout the entire projected 35-year duration of the contracts, then the (significantly understated) scale of the opportunity costs over this period would amount to some £30 billion. And this is exactly the figure given by the NAO for the "top up payments" associated with the unfavorable contract for Hinkley Point C alone (NAO, "Hinkley C", National Audit Office, 23 June 2017). Similar contracts under development for other U.K. civil nuclear stations would significantly add to this figure. And, that offshore wind is also considerably more expensive than onshore wind, with costs of solar power falling even more steeply, further underscores the highly conservative nature of this indicative minimum figure for the total flows of revenue associated with this strategy.

759 - We have some ongoing research, i.e. econometric evidence on the link between nuclear power and military expenditures, that show a bidirectional link between the two, see Lars Sorge et al., "Nuclear Power, Democracy, and Development", presented at the 41st International IAEE conference, 13 June 2018, see http://iaee2018.com/wp-content/uploads/2018/06/Anne-Neumann.pdf, accessed 19 July 2018.

760 - In the presentation (cf. footnote 66) is a graph showing that the share of nuclear in power generation capacity growth is inversely related to the degree of political liberties (a few exceptions of this rule do exist!).

Despite the strong qualitative evidence reviewed in this chapter, analysis of interdependencies, cross-subsidization and strategic complementarities between civil nuclear power and the military sector (especially the nuclear submarine industries), remains undiscussed. Firm quantitative evidence for such links remains lacking, because necessary disaggregated information on flows of revenue, capital, employment and skills are not in the public domain. Yet the secretive nature of the forces at work, is evidently helping prevent definitive conclusions over the scale of the associated impacts on military or energy strategies (see Figure 33).

Figure 33 | Heavily Redacted Pages From a U.K. Defense Ministry Report



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Royal Navy Nuclear Reactor Test Facility Review

support the capital expenditure in costly rigs can be wasted and the capability lost. ***We recommend that the programme produce a comprehensive and funded plan to ensure continued PWR3 through-life verification, validation and test that specifically ensures the sustainment of a suite of current and future test rigs.***

2.1.29 **Suitably Qualified and Experienced Personnel** – People are critical to a successful Naval Nuclear Propulsion Programme. Regardless of adopting the PWR3 design, maintenance of the current fleet and its eventual decommissioning is non-negotiable. The gap in the production of nuclear-powered submarines between the VANGUARD and ASTUTE classes coupled with a long period of depressed activity in the UK's civil nuclear sector has led to significant reductions in the skills base for nuclear plant design, manufacture, support and repair. Across the enterprise the availability of deep specialist expertise in key [redacted] and suitably qualified staff appears to be at the bare minimum necessary to deliver the programme. The programme also has no 'strength in depth' in some fields where it is often overly reliant on individual experts. We believe the Naval Nuclear Propulsion Programme could soon be facing a 'perfect storm' with an ageing expert community facing competition from a resurgent civil nuclear industry and other industries (such as oil and gas) at the same time as the programme is increasing and becoming more diverse [redacted]

2.1.30 Staff within the programme and its cadre of world leading independent experts, have supported the programme for many years (decades in some cases). They are ageing and there is an urgent need to pass on knowledge and develop the next generation. While there have been some successes in industry (for example the AMEC programme to recruit and develop young scientists and engineers), the general age distribution within the defence nuclear business is too strongly skewed towards the upper quartile. We believe there needs to be a reliable pipeline for British citizens to qualify in nuclear professions for both defence and civil sectors and recruit the best and the brightest into the Naval Nuclear Propulsion Programme. ***We recommend that the programme should look at enhancing its presence in universities through diverse mechanisms including sponsorships and summer placements.***

2.1.31 The stop-start nature of contracting a long-term programme together with the tactical approach to procurement and commercial competition risks leading to a fragmented and unsustainable expertise base. Defence will also increasingly be in competition with the revitalised, and better paying, civil programme. ***In order to attract, develop and maintain the necessary pool experts within the Naval Nuclear Propulsion Programme the MOD needs to commit to a long-term technology programme.***

2.1.32 **Residual Vulcan NRTE Capabilities** – The Naval Nuclear Propulsion Programme has made a significant investment in the Shore Test Facility and Vulcan NRTE in general. As it comes to the end of its life there is, within the regulatory limits, an opportunity to undertake [redacted] which could enhance [redacted] knowledge and understanding. ***We recommend that the programme should maximise the investment in the Shore Test Facility to extract as much***

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knowledge and understanding from its operation including considering undertaking [redacted] ***prior to final decommissioning.***

2.1.33 Vulcan NRTE has substantial expertise, knowledge and national niche engineering resources [redacted] – saving the programme money and delivering [redacted] This forms an important element of the overall UK nuclear propulsion capability. We believe strongly that some of these capabilities will need to be maintained in some form or other once Vulcan NRTE closes. ***The programme must ensure that the Vulcan NRTE unique capabilities are regenerated elsewhere within the programme and its substantial expertise and knowledge is retained.***

[redacted]

2.1.35 [redacted] With this need for data, it surprises us that with the Shore Test Facility due for decommissioning its defuel project is still in the concept phase. We are concerned that for past small budgetary savings the MOD chose not to maintain a core [redacted] programme. It will take several years to be in a position to defuel the Shore Test Facility. ***We, therefore, strongly support the programme's decision to continue the Shore Test Facility's operation to enable further investigation of PWR2 operation with a fuel element breach*** [redacted]

2.1.36 We were surprised that Vulcan NRTE was identified as the only facility where [redacted] could be undertaken particularly as this

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Source: Robin Grimes et al, "Royal Navy Nuclear Reactor Test Facility Review" Ministry of Defence, 28 October 2014

What is urgently required in order to resolve this picture more clearly is the publication of currently missing crucial data concerning the nature and scale of the flows and interdependencies between civil and military nuclear industries, and a rigorous process of scrutiny involving probing interrogation, dedicated research and robust analysis.

A series of questions remain open. To what extent are current continuing commitments to nuclear power, in particular countries around the world, due to national attachments to parallel military nuclear infrastructures? What is the magnitude of public provision for a shared civil and military strategic base in education, skills, research and key industrial and supply-chain capabilities? How much of the costs of these shared underpinnings for military nuclear ambitions, are being concealed by otherwise uneconomic joint civil-military nuclear infrastructures? How much cheaper might low carbon electricity services be to consumers, if these military pressures for nuclear lock-in were removed, easing a shift to energy efficiency and competitive renewable energy? And if this lock-in is escaped, what opportunities are presented by the current demise of nuclear power, towards also reducing global exposures to military nuclear threats?

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

INTRODUCTION

Governments and citizens recognize that action needs to be taken to avoid the most dangerous consequences of climate change. On the Governmental level, there are 197 Parties to the Convention of the 2015 Paris Agreement, of which, as of May 2018, 176 had ratified it.[761] The countries that have ratified the Agreement have pledged to "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels".[762] The number of countries that are party to the Agreement is larger than those that have signed up to the previous international climate agreements, with 114 countries having agreed to the Copenhagen Accord, and 192 parties to the Kyoto Protocol.[763]

While research undertaken by the Pew Research Center[764] shows that climate change is an important public issue, as it was identified by people around the world as the second only to concerns over ISIS, as the most serious threat to national security, with an average of 60 percent of those surveyed identifying it as a threat, from a list of eight options. Notably citizens of countries in Europe, North and Latin America, and Africa, identified climate change as their top concern.

Global support for a renewable led energy transition is also high. The Danish renewable firm Ørsted, formerly known as Dong Energy, launched what they describe as the largest ever study of attitudes on the green transition. The online survey was conducted in Canada, China, Denmark, France, Germany, Japan, the Netherlands, Poland, South Korea, Sweden, Taiwan, the U.K. and the U.S.. The barometer reports that 82 percent, of those surveyed, think that it is important to create a world that is fully powered by renewable energy, with the highest national share seen in China, with 93 percent support, and the lowest in Japan, 73 percent.[765]

CO_2 emission from the energy sector is responsible for two thirds of global Greenhouse gas emissions, of which the power sector contributes about half—thus around 33 percent of the total. However, the decarbonization of the electricity industry is also important because the technologies are available today to produce electricity without or with very little CO_2.

761 - UNFCCC, "Paris Agreement - Status of Ratification", United Nations Framework Convention on Climate Change, Undated, see https://unfccc.int/process/the-paris-agreement/status-of-ratification, accessed 22 May 2018.

762 - UNFCCC, "Paris Agreement", see https://unfccc.int/sites/default/files/paris_agreement_english_.pdf, accessed 31 May 2018.

763 - UNFCCC, "The Kyoto Protocol—Status of Ratification", Undated, see https://unfccc.int/process/the-kyoto-protocol/status-of-ratification, accessed 22 May 2018.

764 - Jacob Poushter, Dorothy Manevich, "Globally, People Point to ISIS and Climate Change as Leading Security Threats", Pew Research Center's Global Attitudes Project, 1 August 2017, see http://www.pewglobal.org/2017/08/01/globally-people-point-to-isis-and-climate-change-as-leading-security-threats/, accessed 27 June 2018.

765 - Adelman Intelligence, "Green Energy Barometer", Orsted, 2017, see https://orsted.com/-/media/WWW/Docs/Corp/COM/Barometer-campaign/Green-Energy-Barometer-2017_with-appendix.ashx?la=en&hash=65C5D0F30494C277249CA7622AF0229AD5B6D3CB, accessed 9 June 2018.

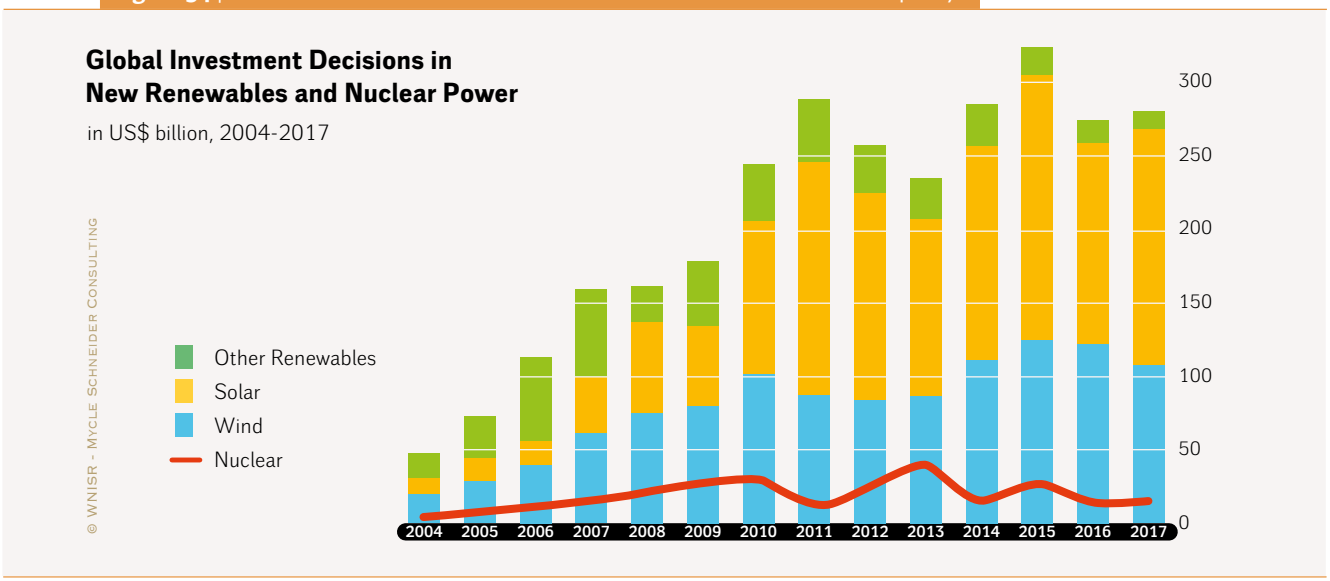
For decades, the mitigation narrative has been that to reduce emissions from the power sector, a combination of renewable energy, fossil fuels with carbon capture and storage (CCS) and nuclear power would be needed. However, the strength of this narrative and argumentation is fading as the deployment rates, costs, technical viability and public acceptance of the different technologies becomes clearer. A study published by *Renewable and Sustainable Energy Reviews*, which assessed 100% renewable energy scenarios and the criticisms of them and settled: "We conclude that the 100% renewable energy scenarios proposed in the literature are not just feasible, but also viable."[766]

However, the debate on the viability of a 100% renewable power system and the possible role for nuclear power and carbon capture and storage will ultimately not be settled in academia or industry forecasts, but in the real world. This chapter reviews the deployment of renewables and nuclear power, using the lenses of investment, deployment and electricity production.

INVESTMENT

The investment decisions taken are not only an important indicator of the future power mix, but they also highlight the confidence that the technology-neutral financial sector has in different power generation options. Consequently, they can be seen as an important barometer of the current state of policy certainty and costs of technologies on the global and regional levels.

Figure 34 | Global Investment Decisions in Renewables and Nuclear Power 2004-2017



Source: FS-UNEP/BNEF 2018 and WNISR Original Research

Figure 34 compares the annual investment decisions for the construction of new nuclear with those for renewable energy since 2004. Construction began on five new reactors in 2017—comparing to three in 2016 and eight new projects in 2015. All of the new-builds were in Asia, but, surprisingly, no construction start of a commercial reactor occurred in China (see China Focus). Besides the launch of a demonstration fast reactor in China, new construction

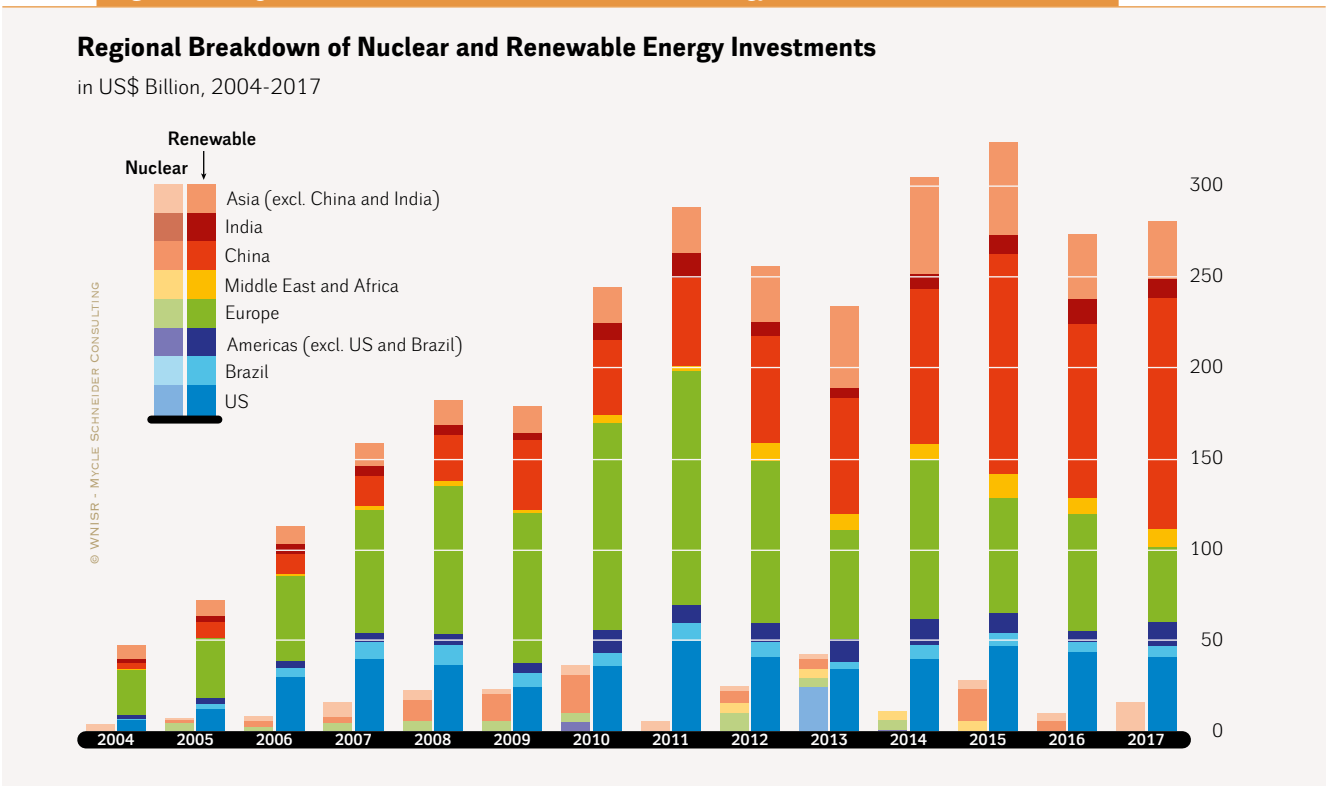
766 - T.A. Brown et al., "Response to 'Burden of proof: A Comprehensive review of the feasibility of 100% renewable-electricity systems", *Renewable and Sustainable Energy Reviews*, see https://www.sciencedirect.com/science/article/pii/S1364032117304495, accessed 24 August 2018.

projects started in Bangladesh, India (two reactors) and the Republic of Korea. The total reported investment for the construction of these projects (excluding the CFR-600) is nearly US$16 billion for 4.25 GW. This compares to over US$100 billion investment in wind power and US$160 billion in solar photovoltaics (PV). In the absence of comprehensive, publicly available investment estimates for nuclear power by year, and in order 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, the nuclear investment figures do not include revised budgets if cost overruns occur.

According to the data published by Bloomberg New Energy Finance (BNEF) and United Nations Environment Program (UNEP), global investment in renewable energy—excluding large hydro[767]—was US$279.6 billion in 2017, up two percent from the US$274 billion the previous year, but down from the global record high US$323.4 billion in 2015.[768]

Globally, the relative importance of Europe and North America for renewable energy investments is diminishing, with the rise of Asia, especially China, India and Japan (see Figure 35). Chinese nominal-dollar renewable investment rose by a factor of 42 from US$3 billion in 2004 to US$126 billion in 2017. Total *cumulated* investment in nuclear in China over the same period was about US$90 billion.

Figure 35 | Regional Breakdown of Nuclear and Renewable Energy Investment Decisions 2004-2017



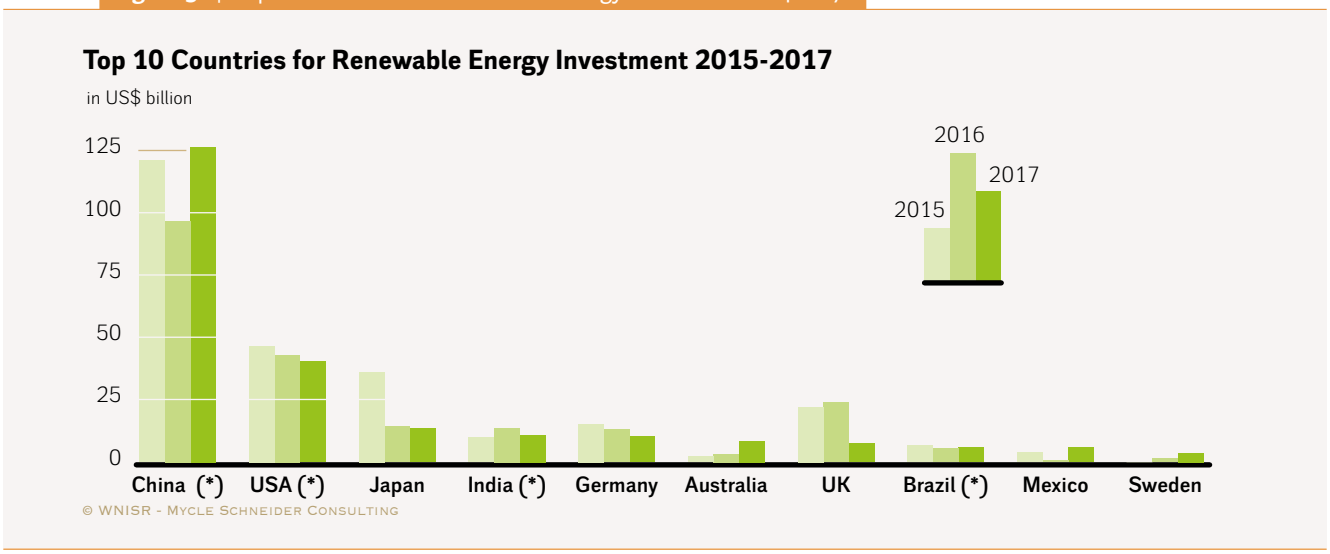
Sources: FS-UNEP/BNEF, WNISR 2018

767 - Note: This chapter systematically excludes large hydro from renewables unless noted otherwise.

768 - Frankfurt School-UNEP Centre for Climate & Sustainable Energy Finance, Bloomberg New Energy Finance, "Global Trends in Renewable Energy Investment Report 2018", United National Environment Programme, April 2018, see http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf, accessed 6 April 2018.

China is obviously leading the Top-Ten of renewable energy investors by a factor of three ahead of the U.S., number two with US$40.5 billion (see Figure 36). Sweden has entered, and Mexico re-entered the Top-Ten, while Belgium and France have been left behind. Particularly remarkable developments, besides the spectacular 61-percent jump of China, are Australia's 158 percent surge from US$3.3 billion to US$8.5 billion and Mexico's factor-9 jump from US$0.7 billion to US$6 billion.

Figure 36 | Top 10 Countries for Renewable Energy Investment 2014-2017



Source: FS-UNEP/BNEF 2018, 2017, 2016

Notes

(*) Updated data for 2015, 2016 and 2017 from FS-UNEP 2018 Report

While there has been a slowdown in the rate of increase of investment this reflects changes in policies in some countries and regions but also, more significantly, the rapid reduction in investment costs per MW as total renewable capacities installed in 2017 added up to 157 GW, significantly larger (+13 percent) than the 138.5 GW in 2016.[769]

Levelized Cost of Energy (LCOE) analysis undertaken by Lazard at the end of 2017 (see Figure 37), suggests that the cost of Solar PV (thin film) ranges from US$43-48/MWh, onshore wind is US$30-60/MWh and nuclear is US$112-143/MWh. The costs of renewables are now also below that of coal (US$60-143/MWh) and combined cycle gas (US$42-78/MWh). Between 2009 and 2017, utility-scale solar costs came down 86 percent and wind 67 percent, according to Lazard.[770]

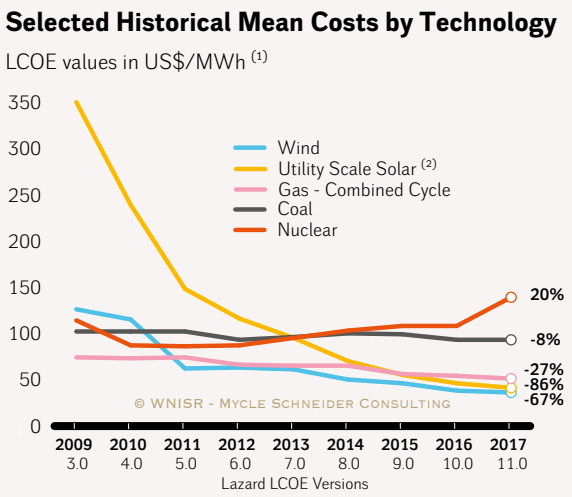
According to an International Renewable Energy Agency (IRENA) estimate, the global weighted average LCOE of utility-scale PV plants has fallen by 73 percent between 2010 and 2017, from around US$0.36 [US$360/MWh] to US$0.10/kWh [US$100/MWh], coming well into the cost range of fossil fuels. IRENA also stated that record low auction prices in 2016 and 2017 "confirm that the LCOE can be reduced to US$0.03/kWh [US$30/MWh] from 2018

769 - Ibidem.

770 - Lazard, "Levelized Cost of Energy 2017—Version 11.0", 2 November 2017, see https://www.lazard.com/perspective/levelized-cost-of-energy-2017/, accessed 9 June 2018.

onward, given the right conditions."[771] Bloomberg New Energy Finance (BNEF) found regional variations, with particularly low onshore wind costs in Australia, India and Sweden and for solar in Australia, Chile, India and Jordan.[772] Examples of some of the projects are a wind auction in Mexico, which guaranteed payments of US$17/MWh and in the UAE with an agreed for solar provision of US$24.4/MWh. While there are many differences between each of these contracts, such as payments for connections or land rental and significant differences in the cost of capital, it does demonstrate how widespread renewable deployment is and that costs are falling. These contracts with nuclear power were during 2016-18 reactors started in only five countries and where construction costs are rising.

Figure 37 | The Declining Costs of Renewables vs. Traditional Power Sources



Source: Lazard Estimates,2017[773]

Notes

LCOE = Levelized Cost of Energy

Reflects average of unsubsidized high and low LCOE range for given version of LCOE study.

Primarily relates to North American alternative energy landscape but reflects broader/global cost declines.

1. Reflects total decrease in mean LCOE since the later of Lazard's LCOE—VERSION 3.0 in 2009—or the first year Lazard has tracked the relevant technology.

2. Reflects mean of fixed-tilt (high end) and single-axis tracking (low end) crystalline PV installations.

771 - IRENA, "Renewable Power Generation Costs in 2017", January 2018, see http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf, accessed 27 June 2018.

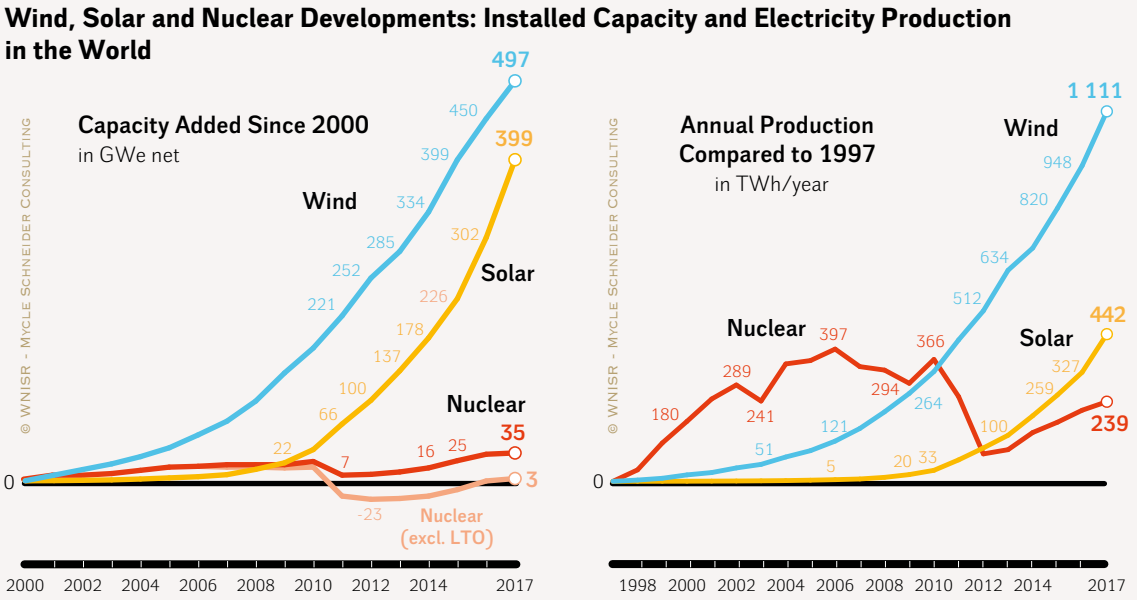
772 - *BNEF*, "Tumbling Costs for Wind, Solar, Batteries Are Squeezing Fossil Fuels", 28 March 2018, see https://about.bnef.com/blog/tumbling-costs-wind-solar-batteries-squeezing-fossil-fuels/, accessed 9 June 2018.

773 - Lazard, "Findings of Lazard's 2017 Levelized Cost of Energy Analysis", Undated, see https://www.lazard.com/media/450436/rehcd3.jpg accessed, 14 August 2018.

INSTALLED CAPACITY AND ELECTRICITY GENERATION

Globally, renewable energy continues to dominate new capacity additions. In total 157 GW of renewables capacity was added in 2017, according to the United Nations Environment Program and Bloomberg New Energy Finance (UNEP/BNEF), which was the largest increase ever, up from 143 GW the previous year.

Figure 38 | Wind, Solar and Nuclear Capacity and Electricity Production in the World



Sources: WNISR, IAEA-PRIS, BP Statistical Review, 2018

In 2017, renewables accounted for 61 percent of net additions to global power generating capacity, up from 57 percent in 2016, and are now providing 19 percent of the total installed capacity.[774] The net capacity additions of wind power slowed down for the second year with 52 GW added compared to 55 GW in 2016 and 64 GW in 2015. On the other hand, solar photovoltaics (PV) is going from strength to strength with a new record of 97 GW installed in 2017, up from 75 GW (+29 percent) the previous year and 51 GW in 2015. The growth is expected to continue in solar in 2018, with business platform IHS Markit forecasting 113 GW for 2018.[775] In the last three years the net nuclear capacity connected to the world's grids totaled annually, 2.9 GW in 2017, 9.6 GW in 2016 and 9.5 GW in 2015.

Figure 38 illustrates the extent to which renewables have been deployed at scale since the new millennium, an increase in capacity of 497 GW for wind and of 399 GW for solar, compared to the stagnation of nuclear power capacity, which over this period increased by less than 35 GW,

774 - FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, "Global Trends in Renewable Energy Investment 2018", FS-UNEP/BNEF, 2018, see http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf, accessed 19 August 2018.

775 - IHS, "Global Solar PV Demand Is Forecast to Reach Record 113 GW in 2018", Press Release, 9 April 2018, see http://news.ihsmarkit.com/press-release/technology/global-solar-pv-demand-forecast-reach-record-113-gw-2018-ihs-markit-says, accessed 7 May 2018.

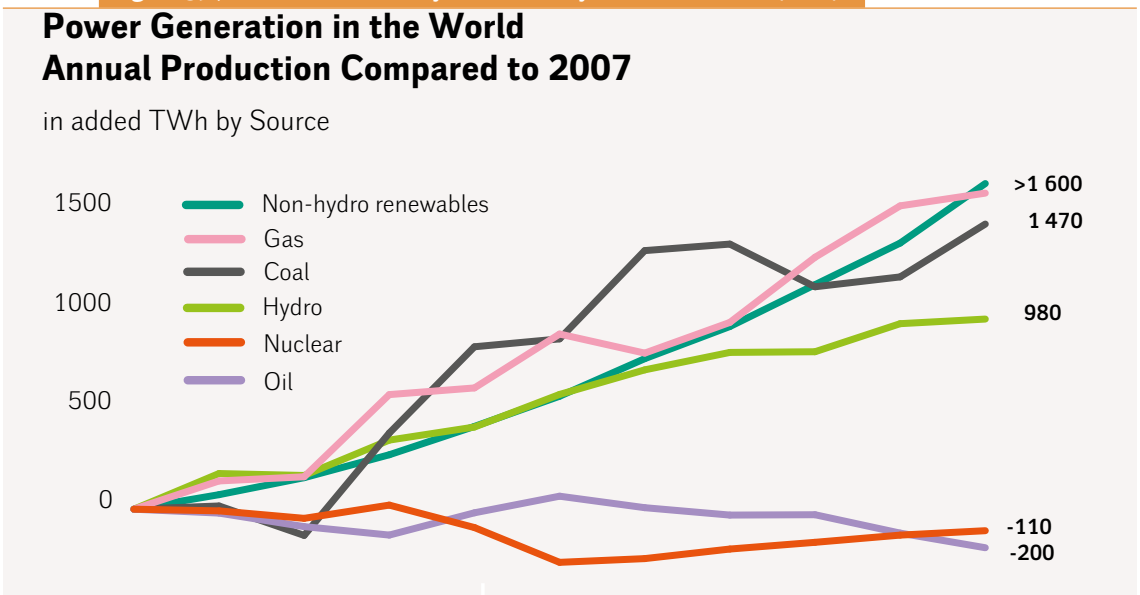
including all reactors currently in LTO. Considering the fact that almost 32 GW of nuclear power were in LTO as of the end of 2017, and thus not operating, the balance is an addition of 2.8 GW compared to 2000.

The characteristics of electricity generating technologies vary due to different load factors. In general, over the year, operating nuclear power plants tend to produce more electricity per MW of installed capacity than renewables.

However, as can be seen in Figure 38, since 1997, there has been an additional 1,111 TWh of wind power in 2017, 442 TWh more electricity from solar photovoltaics (PV), and an additional 239 TWh of nuclear energy. In 2017, annual growth rates for the generation from wind power were 17.3 percent globally, 35 percent for solar PV, and one percent for nuclear power. Nine of the 31 nuclear countries—Brazil, China, Germany, India, Japan, Mexico, Netherlands, Spain and U.K.—generated more electricity in 2017 from non-hydro renewables than from nuclear power.

The growth of renewable energy is now not only outcompeting nuclear power but is rapidly overtaking fossil fuels and the source of choice for new generation. Figure 39 below shows the extent to which, over the last decade different energy sources have increased their electricity production. The energy source that has provided the greatest amount of additional electricity over the last decade is non-hydro renewables, generating an additional 1,675 TWh of power. Of this, 82 percent came from wind and solar. The sector with the second largest growth was gas, followed by coal and hydro, with nuclear power and oil's net production decreasing.

Figure 39 | Net Added Electricity Generation by Power Source 2007-2017

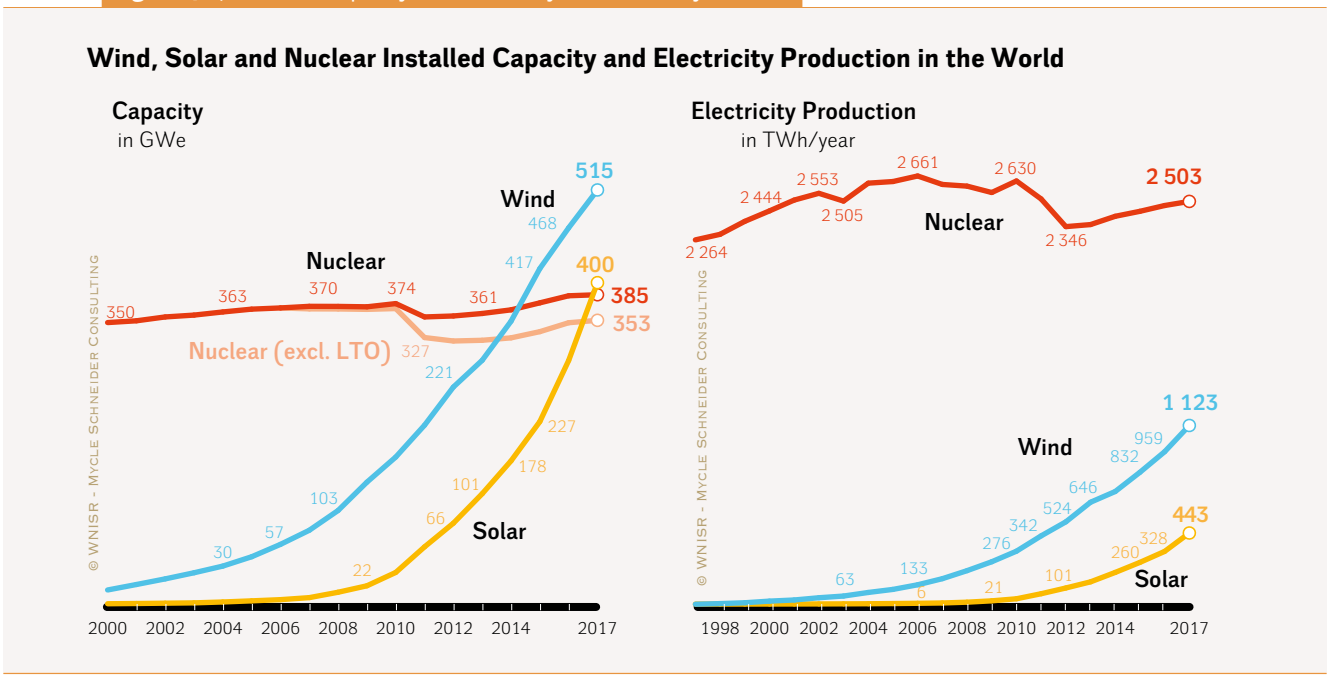


Source: BP Statistical Review (2018)

The International Energy Agency (IEA)'s progress review on the deployment of clean energy, which shows that both solar PV and onshore wind energy are on track to meet their 2-degree scenario. While the IEA states that 8.5 GW per year of new nuclear capacity has been com-

missioned over the last decade, with 20 GW needed, the conclusion is that 'more effort is needed'.[776]

Figure 40 | Installed Capacity and Electricity Generation by Source



Source: WNISR, IAEA-PRIS, BP Statistical Review, 2018

In 2017, worldwide installed solar capacity, that quadrupled in just five years to reach 400 GW, outpaced nuclear capacity with 385 GW (353 GW, excl. capacity in LTO). Wind had passed nuclear capacity in 2015. While nuclear plants still provide more than twice the amount of electricity than wind turbines, five and a half times more than solar—about 2,500 TWh vs. 1,100 TWh and 440 GWh—renewables are catching up quickly (see Figure 40), while nuclear growth is sluggish and very much depending on China (see Figure 41).

STATUS AND TRENDS IN CHINA, THE EU, INDIA, AND THE U.S.

China remains the dominant force in the international renewables and nuclear markets, but domestically, solar and wind are pulling away. Globally, in 2018, China topped the Ernst & Young Country Attractiveness Index for the third year running.[777]

Growth in electricity generation in China has slowed in recent years but is still high compared to the global average. In 2017, the increase was 6.2 percent, below the ten-year average of 7.9 percent. This slowdown has increased competition between the non-fossil generators. Kang Junjie, chief engineer with Dongdian Wanwei Technology, noted that this is favoring re-

776 - IEA, "Tracking Clean Energy Progress 2017", 2017.

777 - EY, "US overtakes India on Renewable energy country attractiveness index despite rising protectionism", 1 May 2018, see http://www.ey.com/gl/en/newsroom/news-releases/news-us-overtakes-india-on-renewable-energy-country-attractiveness-index-despite-rising-protectionism, accessed 6 May 2018.

newables as their costs continue to fall while operating and maintenance costs for nuclear in China are rising.[778]

The solar sector had a record year in 2017 with the deployment of 53 GW of solar PV—more than half of the global total. This was 54 percent higher than in 2016 and is to be compared to the German world record of 7.5 GW annual PV grid connection that dates only from 2012. By the end of 2017 the total installed solar capacity in China was around 130 GW, which now represents 7.2 percent of the total national power capacity.[779] On the other hand the deployment of wind slowed, with 'just' 19.6 GW deployed, which still represents 37 percent of the global market. Wind power capacity in China now totals 188 GW, according to the Global Wind Energy Council,[780] but BP Statistical Review suggests the total is 164 GW (BP is WNISR's reference in this case).

Nuclear power increased its new capacity by about 3 GW, with the completion of just three reactors– Fuqing-4 (1,000 MW), Tianwan-3 (1,060 MW) and Yangjiang-4 (1,000 MW), leading to a total of 34.5 GW. The new reactors started up in China in 2017 represent 90 percent of the global grid connections, with only one other reactor starting up, in Pakistan (built by a Chinese company).

The production of electricity from wind power continues to exceed that of nuclear power, by 53 TWh, with wind now producing 286 TWh, while solar produced electricity now exceeds 100 TWh. On the global scale around a quarter of the world's wind and solar power is produced in China, while it is responsible for less than 10 percent of globally produced nuclear power.

The 13th Five Year Plan (2016-2020) proposes new targets for energy efficiency, 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.[781] Consequently, the explosive growth of renewables is expected to continue. In 2016, a total of 34.5 GW of solar PV were installed, almost double the forecasted 15 to 20 GW per year indicated by the National Energy Administration (NEA).[782] 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 announcement (200 GW), while the target for solar (110 GW) is considerably lower than previous announcements (up to 150 GW). Given the current rhythm of deployment, these are however considered minimum targets and could be exceeded. Indeed, the main bottleneck for further renewable development in China is grid infrastructure, resulting in significant curtailment levels for existing wind and solar power plants.[783] However, reductions in the Feed-in Tariffs, increasing use of auctions, as well as caps

778 - Feng Hao, "Is China losing interest in nuclear power?", *China Dialogue*, 19 March 2018, see https://www.chinadialogue.net/article/show/single/en/10506-Is-China-losing-interest-in-nuclear-power-, accessed 18 June 2018.

779 - *Renewables Now*, "China adds record 53.06 GW of solar in 2017", 19 February 2018, see https://renewablesnow.com/news/china-adds-record-5306-gw-of-solar-in-2017-602234/, accessed 27 May 2018.

780 - GWEC, "Global Wind Report", April 2018.

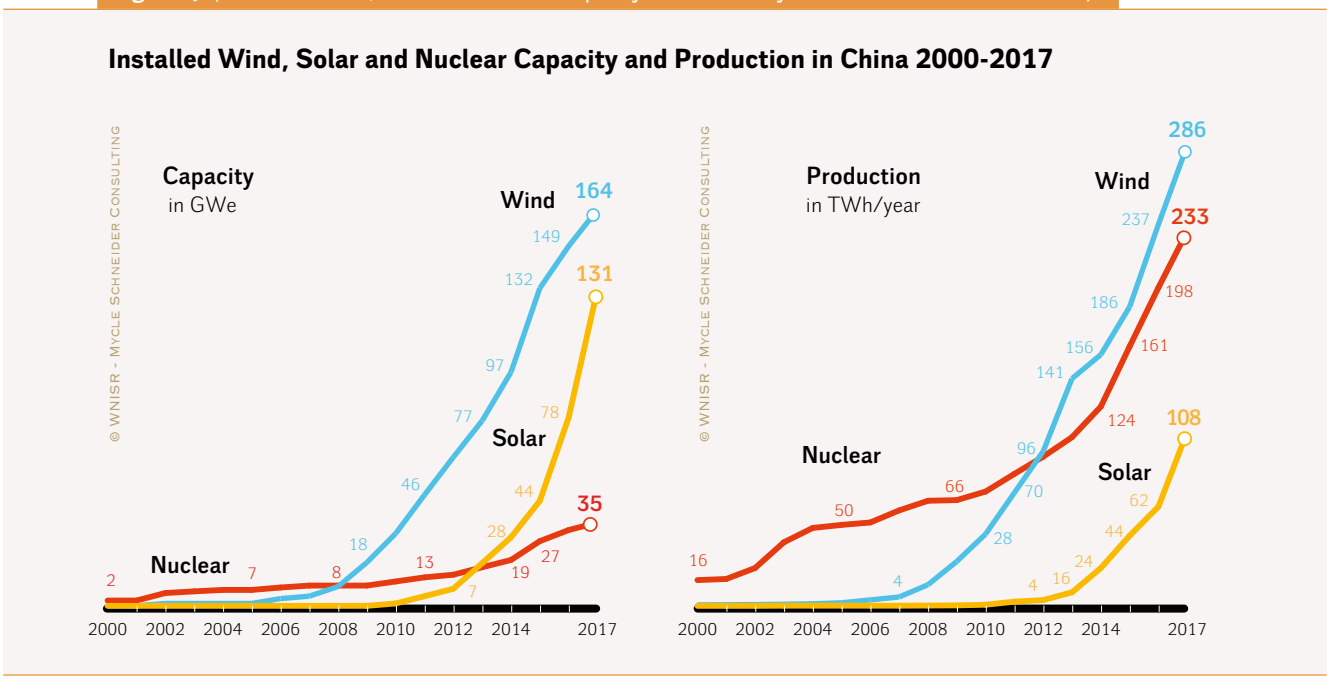
781 - *China Dialogue*, "Climate, energy and China's 13th Five-Year Plan in graphics", 18 March 2017, see https://www.chinadialogue.net/article/show/single/en/8734-Climate-energy-and-China-s-13th-Five-Year-Plan-%20in-graphics, accessed 22 June 2017.

782 - Richard Martin, "China is on an epic solar power binge", *MIT Technology Review*, 22 March 2016, see https://www.technologyreview.com/s/601093/china-is-on-an-epic-solar-power-binge/, accessed 22 June 2017.

783 - Ma Tianjie, "China's Ambitious New Clean Energy Targets", *The Diplomat*, 14 January 2017, see http://thediplomat.com/2017/01/chinas-ambitious-new-clean-energy-targets/, accessed 22 June 2017.

on the subsidization of utility scale auctions have led some analysts to reduce their forecasts for deployment of solar PV, down to 20 GW in 2018.[784]

Figure 41 | Installed Wind, Solar and Nuclear Capacity and Electricity Production in China 2000-2017



Notes pertaining to the Figure above

BP data used for the capacity graph were modified in 2017, in particular due to BP switching primary sources from GWEC to International Renewable Energy Agency (IRENA) for solar, and other revisions based on a new IRENA database. On the generation graph, BP data used were modified from previous years, in particular for solar, where the International Energy Agency (IEA) estimates were replaced with new data from the China Electricity Council starting in 2012.

Sources: BP, IAEA-PRIS, WNISR 2018

The 13th Five Year Plan is also proposing to increase nuclear capacities to a total of 58 GW by 2020. However, only 38.2 GW are currently operating, and another 15.4 GW are under construction, therefore it will be impossible to meet this target.

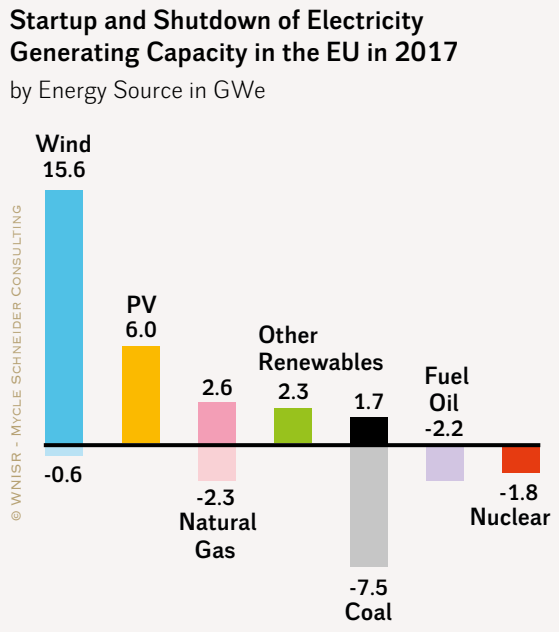
The shift in the market away from nuclear power, while renewables continue to grow rapidly is also affecting the strategies of China's nuclear construction firms. Two of China's big three nuclear constructors, State Power Investment (SPI) and China General Nuclear Power Corporation (CGN) are now among the top 10 global operators of renewable capacity. Over the last three years, CGN has doubled its wind and solar capacity, now operating 13.2 GW accounting for 37 percent of the group's domestic power capacity. The support for renewables amongst the China's nuclear builders is expected to continue as profits from solar and wind exceed that of nuclear. CGN's profit ratio in 2017 for solar was 52 percent, for wind 50 percent but for nuclear only 30 percent.[785]

784 - *Renewables Now*, "GTM cuts by 40% 2018 solar forecast for China", 8 June 2018, see https://renewablesnow.com/news/gtm-cuts-by-40-2018-solar-forecast-for-china-615667/, accessed 27 June 2018.

785 - C.F. Yu, "China - Nuclear Players Shift to Renewables", *NIW*, 6 April 2018.

In the **European Union**, renewables continue to dominate the deployment of new power generating capacity. A total of 23.9 GW of renewables—dominated by wind with 15 GW and Solar PV with 6 GW—was deployed in 2017, which accounted for 85 percent of all added capacity (see Figure 42).[786] Between 2000 and 2017, the net changes in installed generating capacities highlight the shift towards renewables and gas power plants. With respectively 158.3 GW and 107.3 GW, wind and solar power are the generation technologies that saw the biggest development over the past 17 years, with gas power plants coming in at 96.7 GW. On the other end, nuclear capacities decreased by 18.8 GW over the same period, coal by 41.2 GW and fuel oil plants by 40.4 GW.[787] However, despite the increase in renewable deployment in 2017, there has been another year of slowdown in the level of investment in 2017 compared to the previous year (see section on Investments).

Figure 42 | Startup and Shutdown of Electricity Generating Capacity in the EU in 2017



Source: Wind Europe, WNISR, 2018

Other highlights in terms of renewable generation in Europe in 2017-18 include:

- In 2017, wind supplied 11.6 percent of the EU's power, led by Denmark at a remarkable 44 percent, Portugal and Ireland at 24 percent, and Germany at 20 percent and Spain at 19 percent.[788]
- In March 2018, Portugal's renewable energy production exceeded power demand over the entire month, the first time this had occurred for over 40 years, 55 percent of power demand was matched by hydro power and 42 percent from wind.[789]

786 - *Wind Europe*, "Wind in Power 2017", February 2018, see https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf, accessed 27 May 2018.

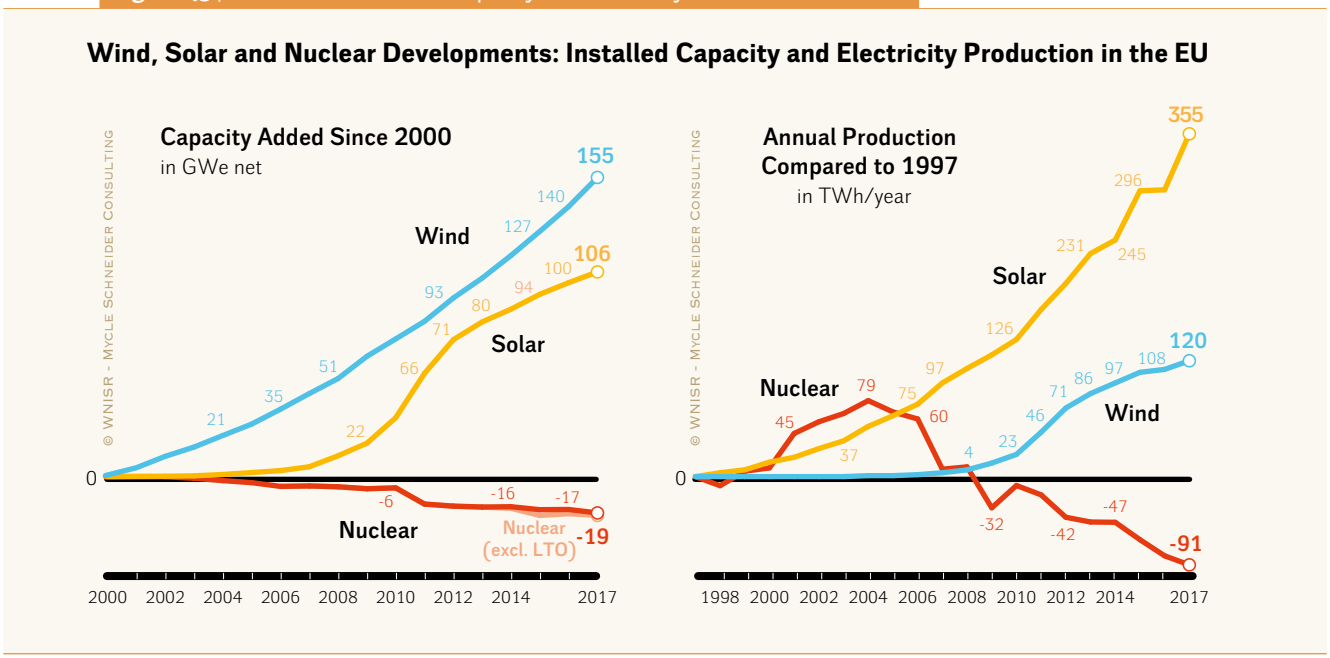
787 - Ibidem.

788 - Wind Europe, "Wind in Power 2017", February 2018.

789 - *Reuters*, "Portugal looks to renewables as March output tops mainland power...", 3 April 2018, see https://www.reuters.com/article/portugal-energy-renewables/portugal-looks-to-renewables-as-march-output-tops-mainland-power-demand-idUSL5N1RG35T, accessed 31 May 2018.

→ In Germany, in 2017, renewables provided about 36 percent of the country's electricity consumption. There are now 43 GW of installed solar at approximately 1.6 million different sites.[790] On 1 May 2018, in the middle of the day, more power was produced from renewable sources than was being consumed in the entire country.[791]

Figure 43 | Variations in Installed Capacity and Electricity Production in the EU



Sources: BP, IAEA-PRIS, WNISR 2018

Compared to 1997, in 2017 wind added 355 TWh and solar 120 TWh, while nuclear power generation declined by 91 TWh or 10 percent across the EU as can be seen in Figure 43.

This growth in renewable electricity production is set to continue beyond the current 2020 targets, as in preparation of the UN 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 mean 50 percent of power coming from renewables. However, in June 2018, it was agreed to increase ambition, with a new target of 32 percent by 2030, with an opportunity to further increase this in 2023.[792] By 2050, the EU aims for a completely carbon-free electricity system. This will require speeding up the current rate of renewable electricity deployment. There is no EU-wide nuclear deployment target and the nuclear share has been shrinking for decades.

India has one of the oldest nuclear programs, starting electricity generation from fission in 1969. It is also one of the most troubled nuclear sectors in the world and has encountered many setbacks (see India section). This is in stark contrast to the extremely rapid increase in the use

790 - Harry Wirth, "Recent Facts about Photovoltaics in Germany", Fraunhofer, February 2018.

791 - Michael Holder, "Renewables cover more than 100 per cent of German power demand on May Day", *Business Green*, 2 May 2018, see https://www.businessgreen.com/bg/news/3031496/renewables-cover-100-per-cent-of-german-power-demand-on-may-day, accessed 31 May 2018.

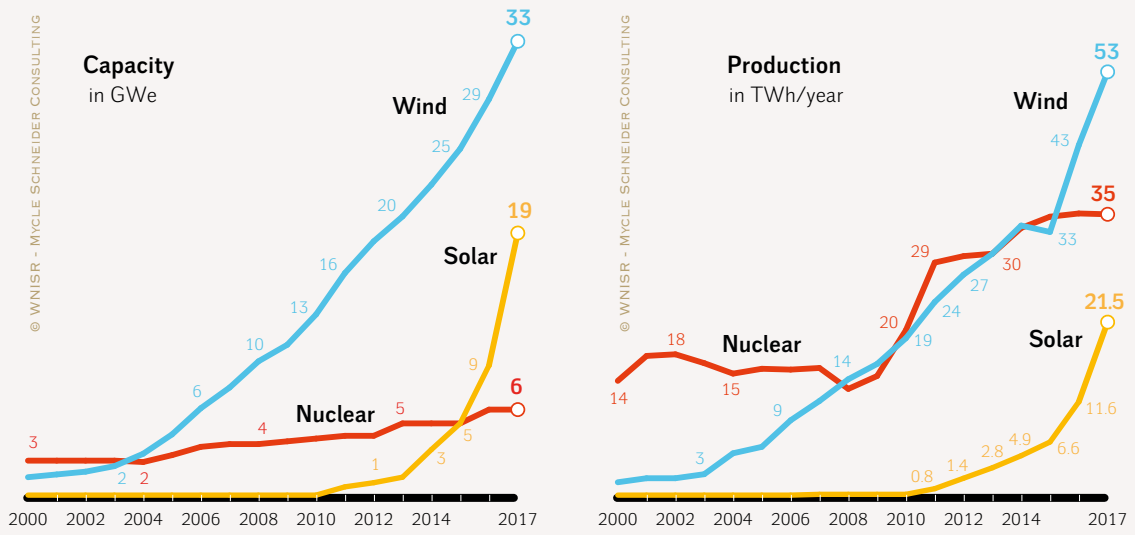
792 - European Commission, "Europe leads the global clean energy transition: Commission welcomes ambitious agreement on further renewable energy development in the EU", 14 June 2018, see http://europa.eu/rapid/press-release_STATEMENT-18-4155_en.htm, accessed 18 June 2018.

of renewable energy. Figure 44 shows, how, since the turn of the century, the wind sector has grown rapidly, from 1.5 TWh to 52.6 TWh in 2017 and has overtaken nuclear's contribution to electricity generation since 2016, which now stands at 35 TWh. While solar is also growing rapidly and has risen from 7 GWh in 2000 to 21 TWh in 2017 and at the current rate of growth is likely to exceed nuclear before the end of the decade. It took nuclear power a decade to increase generation by about 20 TWh, while wind and solar (10 TWh each) combined added the same amount over the last year alone.

At the end of 2017, the country exceeded 70 GW of installed capacities for renewables, with an additional 40 GW under construction or under tender. Since 2014, the capacity of solar has increased from 2.63 GW to 22 GW in mid-2018, while wind increased from 21 GW to 34 GW.[793] The Government further states that it will reach its target of 175 GW of renewable energy capacity well ahead of a 2022-deadline, as bids for the entire amount will be completed by 2020.[794]

Figure 44 | Wind, Solar and Nuclear Installed Capacity and Electricity Production in India

Installed Wind, Solar and Nuclear Capacity and Production in India 2000-2017



Sources: BP, IAEA-PRIS, WNISR 2018

In March 2018, the Solar Energy Corporation of India launched a Request for Proposal (RfP) for tenders to build the country's largest ever solar project, with multiple 250 MW modules leading to the construction of a 3 GW plant. Project developers will be free to choose the location of the projects. The maximum allowed bid for this tender is Rs 2.93/kWh (US$4.5c/kWh).[795]

793 - Ministry of New and Renewable Energy, "A Path breaking Journey in Renewable Energy through last 4 years", 5 June 2018, see http://pib.nic.in/newsite/PrintRelease.aspx?relid=179768, accessed 7 June 2018.

794 - *The Hindu*, "'Will achieve 175 GW renewable energy target well before 2022'", 6 June 2018, see http://www.thehindu.com/todays-paper/tp-business/will-achieve-175-gw-renewable-energy-target-well-before-2022/article24091514.ece, accessed 7 June 2018.

795 - *CleanTechnica*, "India's Largest Solar Tender Of 3 Gigawatts Launched", 12 March 2018, see https://cleantechnica.com/2018/03/12/indias-largest-solar-tender-3-gigawatts-launched/, accessed 7 June 2018.

While auctions for wind power have seen a reduction in prices over the last twelve months from a high of Rs 3.42 (US$5.3c/kWh) to Rs 2.43 (US$3.7c/kWh).[796] 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 about the technology's Levelized Cost of Energy (LCOE) in general and even less for the Kudankulam-3 and -4, where construction started in late 2017. Recent academic analysis in India suggests that costs for light water reactors are between US$13.93-14.13c/kWh depending on the waste management strategy.[797]

In June 2017 President Donald Trump announced that the **United States**, was leaving the Paris Agreement. While this is a significant blow to the international process, it has not led to other countries proposing to withdraw. In addition, although the Government has announced their desire to quit, it cannot be done quickly, and the U.S.'s final exit cannot take place, for procedural reasons, until one day after the next Presidential election. Despite the Government's announcement, climate mitigation action continues to take place on state and city levels, and many of their representatives continue to attend the international negotiations.[798]

During his election campaign Donald Trump pledged to support the coal and nuclear sector, but his efforts to date have not been successful. In 2017, the use of coal in the power sector fell to its lowest level since 1982, and petroleum consumption in the power sector was the lowest on record. While the use of natural gas has increased, overall fossil fuel use is declining and is at its lowest since 1994.[799] However, the administration is still determined to support both coal and nuclear power, with new measures being suggested that would require power grid operators buy electricity from struggling plants over the next two years.[800] Although, there is no doubt that where these suggested plans will be bought forward, they are likely to be challenged in the courts. (See United States Focus for details).

In addition to the relatively low price of gas, the coal and nuclear sectors are being challenged by flat or decreasing power demand and the rise in the use of renewable energy. Electricity sales fell by 80 billion kWh (2 percent} in 2017, the largest drop since the economic recession in 2009.[801] The longer-term downward trend is largely due to the introduction of more energy efficient appliances, in particular LED lights and shifts in the economy.[802]

In 2017, around 28.5 GW of electricity generating infrastructure was deployed—25 GW of it utility-scale and about 3.5 GW of distributed (<1MW) solar power—of which wind and solar were 55.4 percent. However, when looking at net additions with the closure of 11.8 GW of uti-

796 - Saurabh Mahapatra, "Wind Energy Tariffs Rise In India's State-Level Auction", *CleanTechnica*, 14 March 2018, see https://cleantechnica.com/2018/03/14/wind-energy-tariffs-rise-indias-state-level-auction/, accessed 9 June 2018.

797 - Anoop Singh, Saurabh Sharma and M S Kalra, "Levelised Cost of Electricity for Nuclear Power Using Light Water Reactor Technology in India", *Economic and Political Weekly*, 10 March 2018.

798 - John Light, "One Year After Trump Ditched the Paris Agreement, Where Are We?", UN Dispatch, 5 June 2018, see https://www.undispatch.com/one-year-after-trump-ditched-the-paris-agreement-where-are-we/, accessed 7 June 2018.

799 - US EIA, "Electric power sector consumption of fossil fuels at lowest level since 1994 - Today in Energy - U.S. Energy Information Administration (EIA)", 29 May 2018, see https://www.eia.gov/todayinenergy/detail.php?id=33543, accessed 7 June 2018.

800 - Jeff Brady, "President Trump Orders Help For Coal And Nuclear Plants", *NPR*, 1 June 2018, see https://www.npr.org/2018/06/01/616245180/president-trump-orders-help-for-coal-and-nuclear-plants, accessed 7 June 2018.

801 - U.S.EIA, "In 2017, U.S. electricity sales fell by the greatest amount since the recession", 3 April 2018, see https://www.eia.gov/todayinenergy/detail.php?id=35612, accessed 7 June 2018.

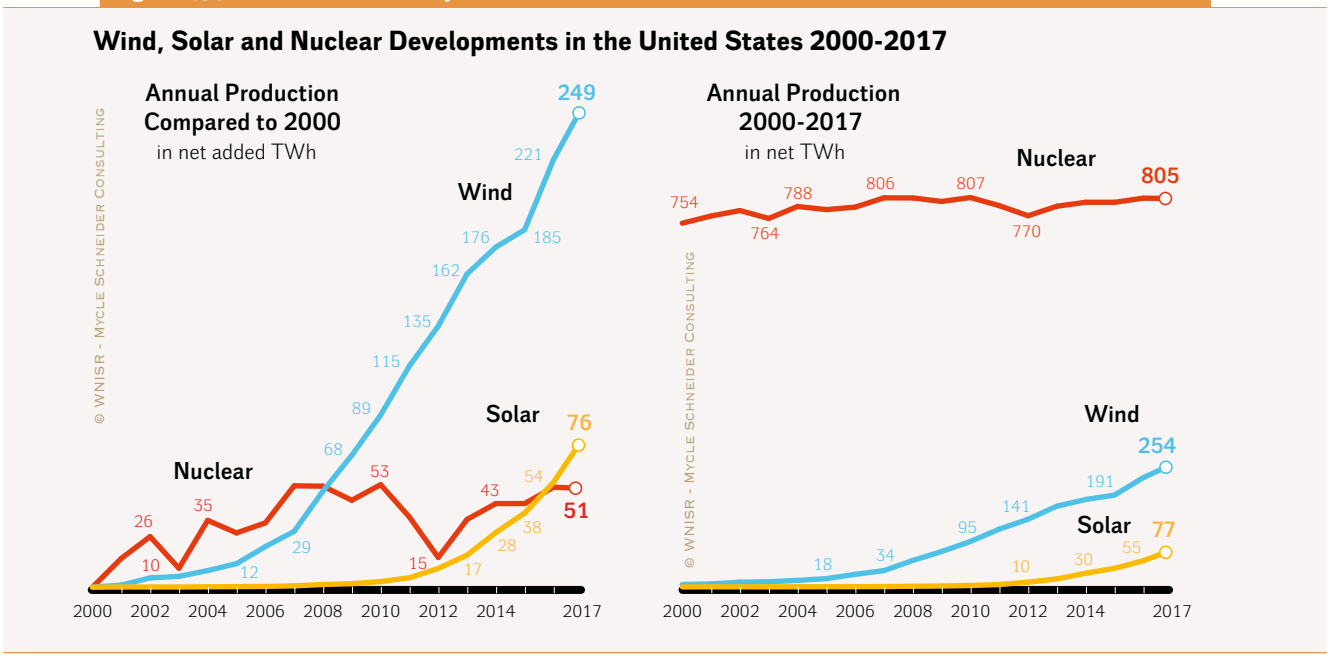
802 - Justine Fox, "Americans Keep Using Less Electricity", *Bloomberg*, 1 March 2018, see https://www.bloomberg.com/view/articles/2018-03-01/americans-electricity-use-just-keeps-falling, accessed 7 June 2018.

lity-scale fossil fuel plant retirements, the net new volume of U.S. generation was 16.7 GW of generating capacity, with 94.7 percent of that coming from renewables.[803]

In March, and again in April 2017, monthly electricity generation from utility-scale renewable sources exceeded nuclear generation for the first time since July 1984. However, the annual contribution of wind and solar is still relatively low, despite their growth, as they start from a low base, with wind power providing 6.3 percent of total net generation, and utility-scale solar 1.3 percent, with small scale solar bringing the total closer to 2 percent. Renewables total, including biomass and hydro provide about 17 percent of electricity generated, compared to about 20 percent from nuclear power.

However, since the turn of the century the growth in the use of solar and wind has significantly outstripped that of nuclear power, as can be seen Figure 45, wind additions overtook nuclear power in the middle of last decade and solar in 2016. According to EY, the U.S. has now overtaken India on their renewable energy country attractiveness index and is now second, behind China.[804]

Figure 45 | Increases in Electricity Production from Nuclear, Solar and Wind Since 2000 in the United States



Source: U.S.DOE EIA, 2018

CONCLUSION ON NUCLEAR POWER VS. RENEWABLE ENERGIES

The different trajectories of solar and wind and that of nuclear power are plain to see. Measured through the lenses of investment, costs, installed capacity and growth in electricity produc-

803 - John Fitzgerald Weaver, "More than 94% of net new electricity capacity in the USA from renewables in 2017 – emissions down 1%", *Electrek*, 12 January 2018, see https://electrek.co/2018/01/12/94-percent-new-electricity-capacity-usa-from-renewables/, accessed 7 June 2018.

804 - EY, "Renewable energy country attractiveness index—Reccai", Issue 51, see https://emeia.ey-vx.com/4864/106523/landing-pages/recai-51-may-2018.pdf, accessed 6 May 2018.

tion, the renewable technologies far exceed, sometimes by orders of magnitude, the statistics for nuclear power.

The modular nature of solar and wind, have enabled enlarged production levels to be translated into falling installation prices and LCOE. With relatively large numbers of manufacturers, compared to the handful of nuclear reactor builders, global competition has further driven down renewable prices. Consequently, the costs of solar and wind are far lower than for nuclear power and even the International Energy Agency (IEA), which is traditionally conservative over deployment of renewable energy have said, "Solar is forging ahead in global power markets as it becomes the cheapest source of electricity generation in many places, including China and India."[805] As this is demonstrated in more and more countries, so production costs for renewables will continue to fall and the experience of integrated solar and wind will increase, leading to lower overall system costs. These processes will further decrease the attractiveness of nuclear power with its large, centralized, capital intensive and inflexible generation.

There is every reason to believe that renewables will, in virtually all markets and systems, be the preferred option over nuclear power. Furthermore, renewables are now also the preferred source of power in most cases over fossil fuels.

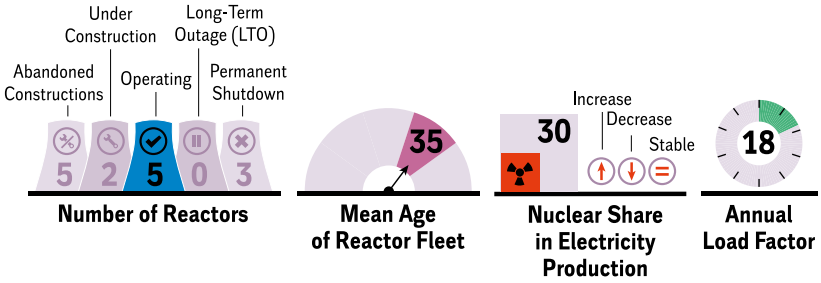
805 - IEA, "World Energy Outlook 2017", 14 November 2017, see https://www.iea.org/newsroom/news/2017/november/a-world-in-transformation-world-energy-outlook-2017.html, accessed 9 June 2018.

ANNEXES

ANNEX 1
OVERVIEW BY REGION AND COUNTRY

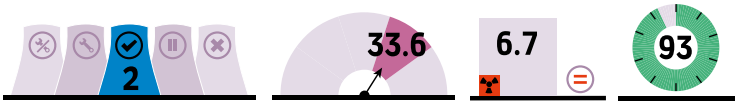
This annex provides an overview of nuclear energy worldwide by region and country that is not covered as Focus Country in the main text (China, France, Germany, Japan, South Korea, U.K. and U.S.). Unless otherwise noted, data on the numbers of reactors operating and under construction (as of mid-2018) and nuclear's share in electricity generation are from the International Atomic Energy Agency's Power Reactor Information System (PRIS) online database.[806] 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*).[807]

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



AFRICA

South Africa



South Africa operates two French (Framatome/AREVA) 900 MW reactors. They are both located at the Koeberg site, north of Cape Town, and generated 15.1 TWh in 2017 providing 6.7 percent of the country's electricity. These figures have hardly moved from the 15.2 TWh and a share of 6.6 percent in 2016 (the historical maximum was 7.4 percent in 1989). The two reactors have improved their load factors in 2017, averaging 92.7 percent, significantly above their lifetime average of 70.4 percent.

The Koeberg plant is the only nuclear power station on the African continent.

The Koeberg reactors are increasingly struggling with ageing issues, having started up in 1984 and 1985 respectively. The decision to replace all six steam generators of the two units was taken in 2010. The plant has been operating at low temperatures to reduce the pace of corrosion in the steam generator tubes. Replacement work is still to begin in 2018 after AREVA was

806 - IAEA-PRIS, "Nuclear Share of Electricity Generation in 2017", see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx, accessed July 2018. In this table, the nuclear electricity supplied is the sum of monthly electricity production of individual reactor units (net). The share of nuclear in electricity generation is provided by the countries, and the basis can differ from the electricity production provided by PRIS, according to statistical method used in each country, and can be based on gross or net production.

807 - *NEI*, "Load Factors to End 2017", May 2018.

awarded the contract in 2014[808] and a lengthy legal battle with competitor Westinghouse (see previous WNISR editions).

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 scale of investment was too high and threatened its credit-rating. In February 2012, the Department of Energy (DOE) published a Revised Strategic Plan 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.[809] The total price of the project was estimated to be in the range of US$37-100 billion.[810]

In April 2017, the Western Cape division of South Africa's High Court upheld two NGOs, the Southern African Faith Communities Environment Institute (SAFCEI) and Earthlife Africa, challenges against the Government. These were, a December 2015 decision to proceed with the procurement of 9.6 GW of new nuclear capacity and that this was to be led by Eskom rather than the DOE, and 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.[811] In May 2017, the Government announced that it would not appeal the decision of the court. The 2018 Goldman environmental prize was awarded to grassroots activists Makoma Lekalakala and Liz McDaid for the successful legal challenge against South Africa's plans to buy nuclear reactors from Russia.[812]

In parallel to these developments, the South African government has been reviewing the expected demand and need for different energy sources. The November-2013 update of the Integrated Resource Plan (IRP) for Electricity, concluded that "the nuclear decision can possibly be delayed".[813] In October 2016, the DOE began consultations on a revision of the IRP, in which it is suggested that commissioning of new nuclear would, under their base-case scenario, be only in 2037, and only 1,359 MWe, equivalent to one reactor. However, the plan then assumes a massive commissioning program with 20 GW of new nuclear capacity by 2050. The updated IRP is expected to be published in late 2018 and in April the Director General of the DOE said it was in the final stages of review.[814]

Amory Lovins, Chief Scientist of Rocky Mountain Institute, U.S., and Anton Eberhard, Professor at the University of Cape Town, South Africa, undertook a review of South African's

808 - *NEI*, "AREVA to replace steam generators at Koeberg", 19 August 2014, see http://www.neimagazine.com/news/newsareva-to-replace-steam-generators-at-koeberg-4346550/, accessed 1 May 2018.

809 - Department of Energy, "Revised strategic plan, 2011/12-2015/16", Republic of South Africa, 2012, see http://www.energy.gov.za/files/aboutus/DoE_RevisedStrategicPlan_2011_12-2015_16%20.pdf, accessed 1 May 2018.

810 - *NEI*, "Eskom plans RFP for new reactors by mid-year", 15 March 2017, see http://www.neimagazine.com/news/newseskom-plans-rfp-for-new-reactors-by-mid-year-5761595/, accessed 1 May 2018.

811 - Phil Chaffee, "Legal, High Court Upends South African Newbuild Plans", *NIW*, 28 April 2017.

812 - Jonathan Watts, "Goldman prize awarded to South African women who stopped an international nuclear deal", *The Guardian*, 23 April 2018, see http://www.theguardian.com/world/2018/apr/23/goldman-prize-awarded-to-south-african-women-who-stopped-an-international-nuclear-deal, accessed 1 May 2018.

813 - DoE, "Integrated Resource Plan for Electricity (IRP) 2010-2030—Update Report 2013", Republic of South Africa, see http://www.doe-irp.co.za/content/IRP2010_updatea.pdf, accessed 1 May 2018.

814 - Terence Creamer, "'High priority' IRP update to be published soon", *Engineering News*, 10 April 2018, see http://www.engineeringnews.co.za/article/high-priority-irp-update-to-be-published-soon-2018-04-10, accessed 1 May 2018.

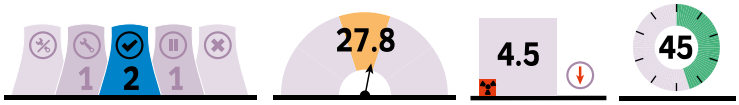
electricity sector, including an assessment of the IRP and nuclear proposals. Their conclusions, released in January 2018, stated:

> Not just Russian but any nuclear new-build is a poor choice for South Africa. It cannot compete with efficiency and renewables, by every relevant measure: cost, timeliness, financing, jobs, economic development, environmental and safety risk, independence, security, abundance of eternally free local energy sources, and the social good of "energy democracy.[815]

The Government is starting to downplay the future role of nuclear power, with the Energy Minister David Mahlobo, stating in December 2017, that saying that its role in the future had come down.[816] Then, in January 2018, President Cyril Ramaphosa said in Davos that "we have no money to go for major nuclear plant building."[817] Even the chief financial officer of Eskom stated: "I can't go and commit to additional expenditure around a nuclear program."[818] President Putin, at the BRICS summit [Brazil, Russia, India, China and South Africa summit] in South Africa in July 2018, reminded President Ramaphosa of the agreement with Russia to build nuclear power plants, but the South African president stated that South Africa neither needs nor can afford nuclear.[819]

THE AMERICAS

Argentina



Argentina operates two nuclear reactors that in 2017 provided 5.7 TWh or 4.5 percent of the country's electricity (down from a maximum of 19.8 percent in 1990). A third reactor is in Long-Term Outage (LTO). One small prototype reactor is under construction. 2018 is expected to be a crucial year for the industry, with construction expected to start on two commercial-size reactors.

Historically Argentina was one of the countries that embarked on an ambiguous nuclear program, officially for civil purposes but backed by a strong military lobby. Nevertheless, the operating nuclear 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 the Canadian Atomic Energy of Canada Limited (AECL) and started operating in 1983. In April 2018, the regulatory authority gave a license to enable Atucha-1 to continue to operate until 2024, thus allowing for a 50-year operating life.[820]

815 - Amory Lovins and Anton Eberhard, "South Africa's Electricity Choice", Graduate School of Business, University of Cape Town, January 2018.

816 - *Reuters*, "UPDATE 2-South Africa to scale down nuclear expansion plan - energy minister", 7 December 2017, see https://uk.reuters.com/article/safrica-nuclear/update-2-south-africa-to-scale-down-nuclear-expansion-plan-energy-minister-idUKL8N1O74Z7, accessed 30 April 2018.

817 - *Reuters*, "South Africa has no money for major nuclear expansion, Ramaphosa says", 25 January 2018, see https://af.reuters.com/article/commoditiesNews/idAFL8N1PK6S9, accessed 1 May 2018.

818 - *NIW*, "Weekly Roundup", 2 February 2018.

819 - *Times Live*, "We can't afford a nuclear deal now, Ramaphosa tells Putin", 26 July 2018, see https://www.timeslive.co.za/politics/2018-07-26-we-cant-afford-a-nuclear-deal-now-ramaphosa-tells-putin/, accessed 10 August 2018.

820 - *WNN*, "Atucha 1 operating licence renewed", 16 April 2018, see http://www.world-nuclear-news.org/RS-Atucha-1-operating-licence-renewed-1604184.html, accessed 7 May 2018.

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.[821] According to World Nuclear Association (WNA), the reactor, which was eventually shut down in January 2016, is expected to come back online in the second half of 2018.[822] *Nuclear Engineering International* (*NEI*) estimated back in 2013 that the whole refurbishment project could take up to five years and cost about US$1.5 billion, warning: "It must be noted, however, that the various Candu refurbishment projects in Canada (Bruce, Pickering and New Brunswick) have tended to overrun on both time and budget."[823] The Embalse reactor entered the LTO category in WNISR2017 as the unit had not restarted by mid-2017.

Atucha-2 was ordered in 1979 and was listed as "under construction" in 1981. Construction was on and off for the next decades, but finally, on 3 June 2014, first criticality was announced, and grid connection was on 27 June 2014. However, it took until 19 February 2015 for the unit to reach full capacity[824] and until 26 May 2016 to enter commercial operation.[825]

For the last decade discussions have been held on the construction of a fourth reactor and in February 2015, Argentina and China ratified an agreement to build an 800 MW CANDU-type reactor at the Atucha site, when Atucha3 was expected to cost US$5.8 billion.[826]

> *"the government announced that it was ending talks with China for the construction"*

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.[827] 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 CANDU6 starting construction in 2018 and the Hualong reactor in 2020.[828] However, the site for the Hualong reactor has not been agreed as the Governor of the Government's preferred location in Rio Negro, said that the reactor would not be located in his province, siting a lack of social acceptance for the project.[829] Despite this, the Government in-

821 - *WNN*, "Embalse refurbishment contracts signed", 25 August 2011, see http://www.world-nuclear-news.org/C-Embalse_refurbishment_contracts_signed-2508114.html, accessed 7 May 2018.

822 - *WNA*, "Nuclear Power in Argentina—Argentinian Nuclear Energy", see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx, accessed 7 May 2018.

823 - Steve Kidd, "Argentina – a possible return to new nuclear?", *NEI*, 15 October 2013, see http://www.neimagazine.com/opinion/opinionargentina-a-possible-return-to-new-nuclear/, accessed 7 May 2018.

824 - *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 7 May 2018.

825 - *WNN*, "Atucha 2 receives full operating licence", see http://www.world-nuclear-news.org/RS-Atucha-2-receives-full-operating-licence-3105165.html, accessed 7 May 2018.

826 - *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 21 March 2018.

827 - Phil Chaffee and Jason Fargo, "Moving closer to Atucha-3 and HPR-1000 Newbuilds", *NIW*.

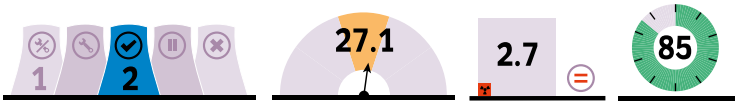
828 - CNNC, "CNNC to build heavy water reactor and HPR 1000 units in Argentina", 19 May 2017, see http://en.cnnc.com.cn/2017-05/19/c_77725.htm, accessed 7 May 2018.

829 - Phil Chaffee, "Argentina", *NIW*, 29 September 2017.

sisted in October 2017, that construction on both projects would begin in the 2nd half of 2018.[830] The total cost of the Hualong and Atucha 3 projects is expected to be US$12.5 billion financed with a 20-year loan from China at an interest rate of 4.5 percent.[831] However, in May 2018, the government announced that it was ending talks with China for the construction of both Atucha3 and for a follow-up Hualong reactor, with some suggestions that this will mean no further development of the projects for at least four years. This will deprive both the Canadian and Chinese developers of one of the few markets they had outside their own countries and might be the end of any serious large-scale nuclear new-build in Latin America.[832]

After repeated delays, construction of a prototype 27 MWe PWR, the domestically designed CAREM25 (Central Argentina de Elementos Modulares—a pressurized-water Small Modular Reactor) began near the Atucha site in February 2014, with startup initially planned for 2018. The reactor is said to cost US$446 million[833], or about US$17,000 per installed kWe, and, as of early 2018, is expected to start up in 2020.[834]

Brazil



Brazil operates two nuclear reactors that provided the country with 14.9 TWh or 2.7 percent of its electricity in 2017, on the same level as in 2016, but 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. In 1975, Brazil signed with Germany a contract for the construction of eight 1.3 GW reactors over a 15-year period. However, only the first reactor, Angra-2, was completed and was finally connected to the grid in July 2000, 24 years after construction started.

Preparatory work for the construction of Angra-3 started in 1984 but was abandoned in June 1991. Then in May 2010, Brazil's Nuclear Energy Commission issued a construction license and the International Atomic Energy Agency (IAEA) noted that a "new" construction started on 1 June 2010. In early 2011, the Brazilian national development bank (BNDES) approved a 6.1 billion-real-(US$3.6-billion)-loan for work on the project.[835] Reportedly, in November 2013, Eletrobras Eletronuclear signed a €1.25 billion (US$1.425 billion) contract with French builder

830 - 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 7 May 2018.

831 - Phil Chaffee, "Argentina", *NIW*, 29 September 2017.

832 - *NIW*, "The Fallout from Argentina's New Build Retreat", 25 May 2018.

833 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2018.

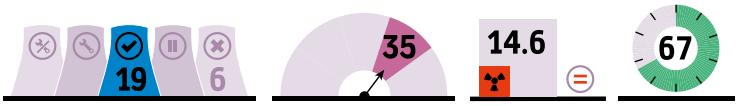
834 - Osvaldo Azpitarte, "Argentina—National nuclear energy status and policies—Activities related to fast reactors", CNEA, presented at the Fiftieth meeting of the IAEA Technical Working Group on Fast Reactors, 15 May 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-05-15-05-18-NPTDS/presentations/presentations/session_1/01_Argentina_TWG-FR_-_Argentina_-_2017.pdf, accessed 24 March 2018.

835 - 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 7 May 2018.

AREVA for the completion of the plant.[836] Commissioning was previously planned for July 2016 but was delayed to May 2018 in 2015[837] and then to May 2019.[838] However, construction was halted in the fall of 2015, as a consequence of a huge corruption scandal.[839, 840]

In January 2017, the Brazilian Official Journal registered Electronuclear's decision to annul the bidding process and the contracts for the electromechanical assembly of Angra-3.[841] CNNC, EDF, Rosatom and Mitsubishi Heavy Industries' joint venture Atmea SAS are now bidding to construct and more importantly finance the project.[842] The Government is hoping to have a new business plan completed in mid-2019 with the aim of completion by 2025, although the key issue remains construction cost and the need to significant raise power prices to pay for it.[843]

Canada



Canada continues to operate 19 CANDU [CANadian Deuterium Uranium] reactors, which, in 2017, produced 95.1 TWh or 14.6 percent of Canada's electricity. The average 12-month load factor and lifetime load factor for Canadian nuclear power plants for the period ending December 2017 as reported by *Nuclear Engineering International* (*NEI*) is 66.6 percent, down from 70.9 percent from the previous year. The 2017 nuclear share in overall electricity generation was also slightly lower than 2016, when it accounted for 15.6 percent. This trend is likely to hold true in the longer-term: the Canadian National Energy Board projects a declining trend for nuclear power; in its 2017 "energy future" report, the reference-case scenario envisions nuclear power capacity declining from 9.7 percent of total installed capacity in 2016 to 6 percent by 2040; the fraction of all electricity generated is expected to come down to around 11 percent in 2040.[844] The nuclear share peaked in 1994 at 19.1 percent.

All of the 19 reactors but one—Point Lepreau in New Brunswick—are located in the province of Ontario, where nuclear power constituted about 35 percent of installed capacity and contributed 63 percent of the electricity produced in 2017.[845]

836 - *WNN*, "Areva contracted to complete Angra 3", 8 November 2013, see http://www.world-nuclear-news.org/C-Areva-contracted-to-complete-Angra-3-081134.html, accessed 7 May 2018.

837 - *NIW*, "Briefs- Brazil", 9 January 2015.

838 - *NIW*, "Newbuild: Sobriety, Secrecy and Reluctance", 24 June 2016.

839 - Jeb Blount, "Brazil police arrest 19 in Eletrobras nuke-plant bribe probe", *Reuters*, 6 July 2016, see https://www.reuters.com/article/us-brazil-corruption/brazil-police-arrests-nine-over-corruption-at-nuclear-plant-idUSKCN0ZM13N, accessed 7 May 2018.

840 - Reese Ewing, "Brazil Eletronuclear CEO gets 43-year sentence for corruption -paper", *Reuters*, 4 August 2016, see https://www.reuters.com/article/brazil-corruption-eletrobras/brazil-eletronuclear-ceo-gets-43-year-sentence-for-corruption-paper-idUSL1N1AL16E, accessed 7 May 2018.

841 - *NEI*, "Contracts for work at Brazil's Angra 3 declared void", 6 February 2017, see http://www.neimagazine.com/news/newscontracts-for-work-at-brazils-angra-3-declared-void-5732236, accessed 7 May 2018.

842 - *NIW*, "Brazil", 15 September 2017.

843 - Luciano Costa, Rodrigo Viga Gaier, "Brazil struggles to find investors in on-again, off-again nuclear...", *Reuters*, 12 January 2018, see https://af.reuters.com/article/commoditiesNews/idAFL4N1P74IW, accessed 7 May 2018.

844 - NEB, "Canada's Energy Future 2017: Energy Supply and Demand Projections to 2040", National Energy Board, 2017, see https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/2017/2017nrgftr-eng.pdf, accessed 8 May 2018.

845 - Independent Electricity System Operator, "Power Data", 5 April 2018, see http://www.ieso.ca/power-data, accessed 5 April 2018.

Most of Canada's electricity, however, comes from renewable sources; in 2016, renewables provided 66 percent of the total electricity generated.[846] This is dominated by hydro power, which contributed nearly 59 percent of all of Canada's electricity generated; of the remaining, wind contributes 4.7 percent, biomass 2.0 percent, and solar 0.5 percent.[847]

"no plans to construct new reactors"

There are no plans to construct new reactors. However, some of the older reactors are being refurbished at significant cost. In 2017, Ontario's Financial Accountability Office (FAO) estimated the total cost of refurbishing ten nuclear reactors at the Bruce and Darlington Generating Stations and extending the life of the Pickering Nuclear Generating Station as CAD25 billion in 2017 dollars.[848] The Office also highlighted four key financial risks to ratepayers, including "the risk that the cost of refurbishing the reactors will be higher or lower than planned", "that the cost of operating the reactors will be higher or lower than planned", the "risk of insufficient electricity grid demand for nuclear generation" and the risk that the Province's commitment to nuclear refurbishment will preclude it from taking advantage of alternative, lower cost, low emissions grid-scale electricity generation options". Although the Office talks about costs of refurbishing being higher or lower, the report itself documents that historically the cost for refurbishment has always been higher than initially budgeted. Likewise, the demand for grid electricity in Ontario declined by 11 percent between 2005 and 2015.[849] Despite these risks, Ontario Power Generation started refurbishing the Darlington nuclear power plant in 2016, and in March 2018, the final calandria tube insert was removed from Unit 2 of Darlington.[850] The refurbishment of all four CANDU reactors at Darlington is currently scheduled to be completed by 2026.

Several small modular reactor development companies continue the process of trying to obtain a safety license. As the first stage, the Canadian Nuclear Safety Commission (CNSC) offers "an optional service" called a "pre-licensing vendor design review", which "is an assessment of a nuclear power plant design based on a vendor's reactor technology". So far ten Small Modular Reactor (SMR) vendors have requested CNSC to undertake such reviews. CNSC clarifies that the "review does not certify a reactor design or involve the issuance of a license under the Nuclear Safety and Control Act, and it is not required as part of the licensing process for a new nuclear power plant. The conclusions of any design review do not bind or otherwise influence decisions made by the Commission".[851]

Although there is evidently no market for SMRs, companies that seek to develop or deploy SMRs claim that they can sell these to isolated communities and mining sites.[852] However, the

846 - NEB, "Canada's Renewable Power Landscape - Energy Market Analysis 2017", December 2017.

847 - Ibidem.

848 - FAO, "An Assessment of the Financial Risks of the Nuclear Refurbishment Plan", 2017.

849 - NEB, "Canada's Renewable Power Landscape—Energy Market Analysis 2017", December 2017.

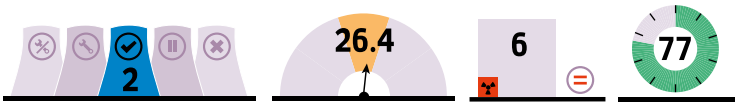
850 - *WNN*, "Darlington refurbishment achieves new milestone", 29 March 2018, see http://www.world-nuclear-news.org/C-Darlington-refurbishment-achieves-new-milestone-2903188.html, accessed 5 April 2018.

851 - CNSC, "Pre-Licensing Vendor Design Review", 18 July 2018, Canadian Nuclear Safety Commission, see http://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm, accessed 30 July 2018.

852 - *WNN*, "Agreement to study SMR use in northern Ontario", 9 April 2018, see http://www.world-nuclear-news.org/NN-Agreement-to-study-SMR-use-in-northern-Ontario-0904185.html, accessed 24 April 2018.

total demand from these is relatively small and is unlikely to allow for economic development of special reactor designs to serve this market.

Mexico



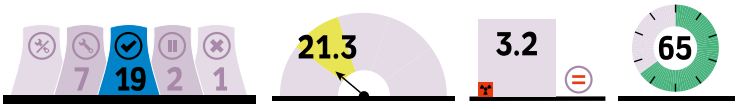
In Mexico, two General Electric (GE) reactors operate at the Laguna Verde power plant, located in Alto Lucero, Veracruz. The first unit was connected to the grid in 1989 and the second unit in 1994. In 2017, nuclear power generation was stable at 10.6 TWh providing 6.0 percent of the country's electricity. The two reactors in Mexico achieved a load factor of 77.1 percent in 2017 marginally above their lifetime average (74.9 percent). The power plant is owned and operated by the Federal Electricity Commission (Comisión Federal de Electricidad).

In September 2015, Cesar Hernandez, deputy energy minister for electricity, said in a *Reuters* interview that his ministry was reviewing "the potential to add a pair of reactors" to the Laguna Verde site.[853] However, he did not indicate anything on timelines, technologies or costs involved and the low price of gas and renewable energy deployment reduce the likelihood of any further nuclear power development. In November 2017, the latest of three renewable energy auctions resulted in a world-record low average price of US$20.57/MWh. As a result of three auctions, contracted solar capacity totals almost 5 GW and US$5 billion investment. The average price level came down from US$44.9/MWh in the first auction to US$31.7/MWh in the second—both were held in 2016. Solar capacity increased 74 percent between 2016 and 2017.[854]

In May 2018, President Trump transmitted to Congress a formal nuclear co-operation agreement, (a "123 agreement"), which is necessary before any nuclear material or equipment export from the U.S. can take place. Congress then has 90 days to review, and if it chooses to reject the proposal, otherwise it will enter into force.[855]

ASIA AND MIDDLE EAST

India



The International Atomic Energy Agency (IAEA) lists India as operating 22 nuclear power reactors, with a total net generating capacity of 6.2 GW. However, according to WNISR criteria, two reactors (Kakrapar-1 and-2) are in the LTO category. These are being refurbished

853 - Adriana Barrera, "UPDATE 1-Mexico eyes construction of two new nuclear reactors...", *Reuters*, 24 September 2015, see https://www.reuters.com/article/mexico-nuclear/update-1-mexico-eyes-construction-of-two-new-nuclear-reactors-official-idUSL1N11U2WA20150924, accessed 7 May 2018.

854 - *PV Magazine International*, "Mexico to hold new power auction including solar in November", see https://www.pv-magazine.com/2018/03/16/mexico-to-hold-new-power-auction-including-solar-in-november/, accessed 1 July 2018.

855 - President Trump, "Presidential Message to the Congress of the United States", The White House, 8 May 2018, see https://www.whitehouse.gov/briefings-statements/presidential-message-congress-united-states-5/, accessed 5 July 2018.

and have not generated power for more than 1.5 years.[856] According to the Indian government, Rajasthan-1 is "under extended shutdown for techno-economic assessment for continued operation" and has not generated any power since 2004. However its final closure was announced in December 2014, and it was moved from LTO to permanent shutdown.[857] The remaining nuclear power plants contributed 34.9 TWh in 2017, the same level as the 35 TWh generated in 2016, and the share of nuclear power declined from 3.4 percent in 2016 to 3.2 percent in 2017. The average annual load factor for 2017 for all of India's reactors was 64.8 percent, down from 66.8 percent in 2016, but still above the lifetime load factor of 57.5 percent.

For the period April 2017 to March 2018, India's fiscal year, the Central Electric Authority (CEA), the country's planning body for electricity, reports that nuclear power generated 38.3 TWh, in comparison to 37.9 TWh during the previous fiscal year.[858] In comparison, renewable energy sources, other than large hydro, together generated 101.8 TWh in 2017-18 as compared to 81.9 TWh in 2016-17, a nearly 25 percent increase. Therefore, the contribution of non-hydro renewables to the electric grid in India is now 2.7 times the electricity contributed by nuclear power plants, and that ratio is up from 2.2 times, just one year ago.

The difference between renewables and nuclear is only set to grow with the rapid increase in installed capacity of wind and solar energy. It is reported that solar photovoltaics (PV) "was the leading source of new power capacity additions in the calendar year 2017 with installed capacity of approximately 9.5 GW accounting for 45 percent of total power capacity additions. Wind was the second most installed power source with 19.6 percent".[859]

No new reactor was connected to the grid during 2017, or the first half of 2018. Two reactors, the third and fourth units of Kudankulam, officially started construction on 29 June and 23 October 2017 respectively. Including those two, there are now seven reactors under construction with a total net capacity of 4.8 GW. The others are the Prototype Fast Breeder Reactor (PFBR), whose construction started in October 2004, and four Pressurized Heavy Water Reactors (PHWRs) at Kakrapar (KAPP 3 & 4) and Rajasthan (RAPP-7 & -8), whose construction started in 2010 and 2011. With the exception of the Kudankulam reactors, all the other construction projects are delayed.

The PFBR, in particular, has now exceeded the expected construction period at the start of the project by over 130 percent, from a little over six years to at least fourteen years. The official

856 - Jitendra Singh, "Unstarred Question No. 6071: Nuclear Power Plants", Lok Sabha, Department of Atomic Energy, Government of India, April 2018, see http://dae.nic.in/writereaddata/parl/budget2018/lsus6071.pdf, accessed 21 May 2018. The official statement about these reactors is that they "have been taken in project mode for Enmasse Coolant Channel Replacement (EMCCR) and Enmasse Feeder Replacement (EMFR) activities from 1 August 2016 onwards". The process involves replacing the pressure tubes and the carbon steel feeders in the primary heat transport system in these reactors. In April 2018, the Nuclear Power Corporation of India Limited (NPCIL) reported that the installation of all coolant channels has been completed for Unit 2 of Kakrapar. See NPCIL, "Report on Major Achievements, Significant Developments and Important events for The Month of April-2018 at Kakrapar Gujarat Site", 2 May 2018, see http://www.npcil.nic.in/WriteReadData/userfiles/file/news02may2018_03.pdf, accessed 16 May 2018.

857 - *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.

858 - Central Electric Authority, "Monthly Generation Report", March 2018, see http://www.cea.nic.in/reports/monthly/generation/2018/March/actual/actual.html, accessed 22 May 2018.

859 - *Mercom India*, "Solar Was the Top Source of New Power Capacity Addition in 2017 For the First Time in India", 16 January 2018, see https://mercomindia.com/solar-top-renewable-source-india-2017/, accessed 30 April 2018.

date for "expected completion" of the PFBR is 2018.[860] But a report in the *Times of India*, a leading newspaper, from March 2018 says that the PFBR "is expected to achieve criticality either in late 2018 or early 2019".[861]

The delay in completion of the PFBR has also affected plans for construction of potential future breeder reactors. In 2005, the director of the Indira Gandhi Centre for Atomic Research (IGCAR), the institution that is developing the designs for breeder reactors in India, forecasted that four more fast breeder reactors, of 500 MW capacity each, would be built by 2020.[862] Now, according to the current director of IGCAR, construction of the next two breeder reactors is expected to begin "by 2021" and the reactors "would be ready for commercial power production by 2029 and 2031 respectively".[863]

Also delayed are the four PHWRs, which use the 700 MW design that the Indian nuclear establishment has evolved over the decades, based on the original 220 MW design imported from Canada.[864] Construction of these four PWHRs started in November 2010 (Kakrapar-1 and -2) and in July 2011 (Rajasthan-7) and September 2011 (Rajasthan-8). All four were to be commissioned between 2015 and late 2016.[865] As of February 2018, the official figures for "physical progress" are 83.2 percent for Kakrapar-3 and -4, and 69.2 percent for Rajasthan-7 and 8, with "expected completion" dates of 2018/19 for the former, and 2020 for the latter.[866] However, the following month, the Minister in charge of Atomic Energy offered 2019/20 as the "expected completion" dates for Kakrapar-3 and -4 and 2020/21 for Rajasthan-7 and -8.[867]

The numbers given for physical progress on the four PHWRs in February 2018 do not suggest that the reactors will actually be operational by the expected completion dates. Further, the physical progress figures often lead one to underestimate the time it will take for the project to be completed: in December 2012, for example, Kudankulam-1 and -2 were said to have achieved a physical progress of 97 percent,[868] but the actual dates for commercial operation were 31 December 2014 for unit 1 and 31 March 2017 for unit 2.

Construction of further PHWRs, including ten 700 MW PHWRs approved by the Government cabinet in May 2017, has not started. The first set of PHWRs after Kakrapar-3 and -4 and Rajasthan-7 and -8 will be at the Gorakhpur site in the northern state of Haryana. Excavation for two reactor units started at the Gorakhpur site in March 2018 and, according to Nuclear

860 - DAE, "Unstarred Question No.4226—Issues Concerning Installation Of New NPPs—Answer by The Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office (Dr. Jitendra Singh)", 21 March 2018, see http://dae.nic.in/writereaddata/parl/budget2018/lsus4226.pdf, accessed 15 May 2018.

861 - Pradeep Kumari, "Kalpakkam Fast Breeder Test Reactor achieves 30 MW power production", *The Times of India*, 27 March 2018, see https://timesofindia.indiatimes.com/city/chennai/kalpakkam-fast-breeder-test-reactor-achieves-30-mw-power-production/articleshow/63480884.cms, accessed 6 April 2018.

862 - *The Hindu,* "Kalpakkam PFBR to be completed ahead of schedule; 4 more to come up by 2020", 7 September 2005.

863 - Pradeep Kumari, "Kalpakkam Fast Breeder Test Reactor achieves 30 MW power production", *The Times of India*, 27 March 2018.

864 - S. A Bhardwaj, "The future 700 MWe pressurized heavy water reactor", *Nuclear Engineering and Design*, 2006.

865 - MoSPI, "37th Report on Mega Projects (Rs. 1000 Crores and above) June, 2012", Ministry of Statistics and Programme Implementation, 2012.

866 - Jitendra Singh, "Starred Question No. 218: Construction of Nuclear Power Projects", DAE, Government of India, March 2018, see http://dae.nic.in/writereaddata/parl/budget2018/rssq218.pdf, accessed 21 May 2018.

867 - Jintendra Singh, "Unstarred Question No.4226—Issues Concerning Installation Of New NPPs—Answer by The Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office", DAE, Government of India, 21 March 2018.

868 - V. Narayanasamy, "Unstarred Question No. 2949: Nuclear Power Plants in the Twelfth Plan", Rajya Sabha, December 2012.

Power Corporation of India Ltd (NPCIL), the project is to cost Rs. 205.9 billion (US$3.2 billion) and "be completed in about six years".[869] The Gorakhpur site was selected in June 2007 and, at that time, eleven years ago, a high-level government official had stated that "work to set up a nuclear power plant in the state would commence soon".[870]

India's plans to import reactors from the United States and France continue to be stalled, with periodic agreements signed, whenever there are visits from heads of states or similar high-level political officials. Thus, for example, in March 2018, on the occasion of French President Macron coming to India, NPCIL and EDF "signed an Industrial Way Forward Agreement for implementation of six nuclear power reactor units at Jaitapur, Maharashtra".[871] The six units are to be all EPRs, the first EPR in the world only started operation in June 2018 in China. The March 2018 agreement, in essence, seems to be an attempt to shift the "construction risk for the proposed six EPRs" from EDF to NPCIL, although "much of the real risk allocation and role allocation will likely only be settled in the final contract", which might take at least one more year to be finalized, if at all.[872] Construction will start only after that. The extent of the delay in the project can be seen from the fact that in 2009, NPCIL officials announced that "groundbreaking is only scheduled for early 2011".[873]

Another high-level functionary to visit India and attempt to revive a stalled nuclear project was U.S. Energy Secretary Rick Perry, who came to India in April 2018 and promised that "Westinghouse Electric Co is emerging out of bankruptcy and is now capable of delivering the planned six nuclear reactors to India on time".[874] Six AP1000s from Westinghouse were first proposed for the Mithi Virdi site in Gujarat in Western India but, faced with opposition from farmers, the site was switched to Kovvada in south eastern India in 2016.[875] The Kovvada site was originally supposed to be the site for six ESBWRs from GE Hitachi,[876] but GE withdrew from nuclear projects in India due to its opposition to India's nuclear liability regime[877]. The plan to build Westinghouse's AP1000 reactors at Kovvada has also been confronted with strong local opposition.[878]

869 - NPCIL, "Excavation starts on first pair of nuclear power reactors in Haryana", Press Release, 24 March 2018, see http://www.npcil.nic.in/writereaddata/Orders/201803241054565793647news_24mar2018_01.pdf, accessed 26 March 2018.

870 - ENS, "Work on nuclear power plant to start soon: CS", *Indian Express*, 21 June 2007.

871 - Jitendra Singh, "Budget Session 2018—Unstarred Question 4325—Agreement Between NPCIL and EDF of France—Written Answer by the Minister of State for Personnel, Public Grevian CES & Pensions, and Prime Minister's Office", DAE, Government of India, 5 April 2018.

872 - Rakesh Sharma, Phil Chaffee, "Jaitapur Agreement Appears to Shift Risk to India", *NIW*, 16 March 2018.

873 - *Hindu Business Line*, "Jaitapur nuclear plant will cost Rs 1-lakh cr", 16 October 2009, see https://www.thehindubusinessline.com/todays-paper/tp-economy/Jaitapur-nuclear-plant-will-cost-Rs-1-lakh-cr/article20063204.ece, accessed 22 May 2018.

874 - PTI, "Westinghouse emerging from bankruptcy, capable of delivering India nuclear reactors: Rick Perry", *Economic Times*, 17 April 2018, see https://economictimes.indiatimes.com/industry/energy/power/westinghouse-emerging-from-bankruptcy-capable-of-delivering-india-nuclear-reactors-rick-perry/articleshow/63796936.cms, accessed 17 April 2018.

875 - *Reuters*, "EXCLUSIVE: Westinghouse to relocate planned nuclear plant to Andhra...", 1 June 2016, see https://in.reuters.com/article/india-westinghouse/exclusive-westinghouse-to-relocate-planned-nuclear-plant-to-andhra-pradesh-officials-say-idINKCN0YM1IV, accessed 30 July 2018.

876 - *Times of India*, "Kovvada nuclear plant to enhance its capacity", 11 July 2013, see https://timesofindia.indiatimes.com/city/visakhapatnam/Kovvada-nuclear-plant-to-enhance-its-capacity/articleshow/21012669.cms, accessed 30 July 2018.

877 - *Reuters*, "GE's Immelt rules out India nuclear investment under current law", 21 September 2015, see https://www.reuters.com/article/us-ge-exim/ges-immelt-rules-out-india-nuclear-investment-under-current-law-idUSKCN0RL0X220150921, accessed 30 July 2018.

878 - *The Wire*, "Activists Protest Against Westinghouse Officials' Visit to Andhra Pradesh's Kovvada", 13 February 2018, see https://thewire.in/energy/westinghouse-kovvada-nuclear-project-andhra-protest, accessed 30 July 2018.

All these delays are impacting even the projections that the government rolls out periodically. In March 2018, the Minister in charge of Atomic Energy stated in the Indian Parliament:

> The present installed nuclear capacity of 6,780 MW would reach 13,480 MW by the year 2024 with the completion of projects under construction (including 500 MW PFBR, being implemented by BHAVINI [Bharatiya Nabhikiya Vidyut Nigam Limited—Indian Nuclear Power Corporation Limited]). In June 2017, the Government accorded administrative approval and financial sanction for 12 more reactors with a total capacity of 9,000 MW, which are scheduled to be completed progressively by 2031. Together with the capacity being implemented by BHAVINI, the total nuclear power capacity will reach 22,480 MW by the year 2031.[879]

The list of projects that constitute the 9,000 MW was also mentioned by the Minister in February 2018 in the Parliament in response to a question about "new projects in the field of atomic energy".[880] That list includes two VVER-1000s at Kudankulam (these would be units 5 and 6) and ten Pressurized Heavy Water Reactors (PHWR) of 700 MW each.

There are at least two key take-away messages from the government announcement that the target for 2031 is 22.5 GW.

First, this is much smaller than the figure of 63 GW by 2032 that the Indian government offered as part of its Nationally Determined Contribution (NDC) communication to the Paris Conference of Parties to the UN Framework Convention on Climate Change; as late as 2017, a senior retired official from the Department of Atomic Energy (DAE) had declared that "the country is progressing to achieve the target of 63 GW by 2032".[881] Unless one believes that about 40 GW of nuclear capacity can come online until 2032, there is a profound mismatch between the nuclear establishment's projections and the government's current expectations. And, based on past experience, even the government's projection of 22.5 GW by 2031 is unlikely to be met.

The second implication of the 22.5 GW by 2031 projection is that the government doesn't have much hope that the two main strategies envisioned for the expansion of nuclear power by the DAE in the last decade and a half—(1) reprocessing spent fuel, constructing large numbers of fast breeder reactors (FBRs), reprocessing again and using the extracted plutonium to fuel new FBRs, and (2) importing large numbers of light water reactors—are going to be implemented within that time frame.

The first strategy was key to DAE's ambitious projections in which nuclear power went up from the few percent of electricity it has historically supplied to somewhere in the 25 to 35 percent range by mid-century.[882] In the earlier projection that only envisioned 25 percent by 2052 and 13 percent by 2032, the DAE projected 45.5 GW of fast breeder reactor capacity operating in

879 - Department of Atomic Energy, "Unstarred Question No. 2064—Share of Atomic Energy", Lok Sabha, Government of India, March 2018, see http://dae.nic.in/writereaddata/parl/budget2018/lsus2064.pdf, accessed 21 May 2018.

880 - Department of Atomic Energy, "Unstarred Question No. 803—New Projects in the Field of Atomic Energy", Lok Sabha, Government of India, February 2018.

881 - R. B. Grover, "India must achieve the target of 63 GW nuclear-installed capacity by 2032", *Economic Times Blog*, 15 July 2017, see https://blogs.economictimes.indiatimes.com/et-commentary/india-must-achieve-the-target-of-63-gw-nuclear-installed-capacity-by-2032/, accessed 23 May 2018.

882 - R. B Grover and Subash Chandra, "Scenario for growth of electricity in India", *Energy Policy, 2006;* Anil Kakodkar, "Evolving Indian Nuclear Energy Programme—Rationale and Perspective", Atomic Energy Commission, presented at the Indian Academy of Sciences, 4 July 2008, see http://www.igcar.gov.in/igc2004/111FILE.pdf, accessed 21 December 2016.

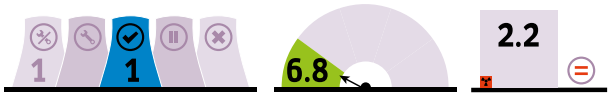
the country by 2032.[883] In comparison, the statement laid in the Indian parliament earlier this year envision 0.5 GW of fast breeder reactor capacity operating in the country by 2032, i.e., just the PFBR that has been under construction since 2004, or about 1.1 percent of the projections made in the first few years of the century.

The second strategy—importing a large number of light water reactors—was the basis of the high-profile negotiations that resulted in what was termed the U.S.-India nuclear deal and the special waiver in 2008 by the Nuclear Suppliers Group to India allowing it to import nuclear power plants without having signed the Nuclear Non Proliferation Treaty.[884] The Minister of Power at that time stated: "We hope that this cooperation with the U.S. will help us add 40,000 MW of nuclear power by the year 2020".[885] In 2008, the head of the DAE specifically indicated plans to import 40 GW of Light Water Reactors (LWRs) during the period 2012-2020.[886]

But now, with the exception of two more VVERs at Kudankulam, the government does not envision any imported reactors to be constructed and operating even by 2031. Thus, despite all the optimistic statements made by Indian government officials, when there are high level visitors coming to India from France or the U.S., even the government itself doesn't expect those projects to come through anytime in the next 13 years.

Soon after the nuclear deal was negotiated, two leading academics predicted that it "will lead to massive reductions in India's emissions relative to the expected level".[887] Given the record so far, there have been no reductions whatsoever.

Iran



Iran has a single operating nuclear power plant (Bushehr-1), which generated 6.37 TWh or 2.17 percent of Iran's electricity in 2017.[888] The share of nuclear energy is almost identical to what it was in 2016. Throughout 2017, the load factor of Bushehr-1 reached the highest value so far of 79.4 percent. The bulk of Iran's electricity comes from natural gas followed by oil.

Work on the second unit (Bushehr-2) has continued to progress slowly and the first pour of concrete, the official construction start, is yet to happen; excavation for the foundation started on 31 October 2017.[889] This is the first of two VVER-1000 reactors contracted to Russia's Rosatom. Last year, it was reported that Bushehr-2 is expected to be commissioned in January 2026, followed by Bushehr-3 two years later.[890] However, Bushehr-2 was listed as "under construction" by the IAEA for more than 10 years, before it disappeared from the list in

883 - Grover and Chandra, "Scenario for Growth of Electricity in India", 2006.

884 - M. V. Ramana, "The Power of Promise: Examining Nuclear Energy in India", Penguin India, 2012.

885 - ToI, "Indo-US nuke cooperation to help add 40,000 MW power: Shinde", *Times of India*, 16 October 2008.

886 - R. B Grover and Subash Chandra, "Scenario for growth of electricity in India", *Energy Policy*, 2006; and Anil Kakodkar, "Evolving Indian Nuclear Energy Programme—Rationale and Perspective", Atomic Energy Commission, presented at the Indian Academy of Sciences, 4 July 2008, see http://www.igcar.gov.in/igc2004/111FILE.pdf, accessed 21 December 2016..

887 - Robert Keohane, David Victor, "The Regime Complex for Climate Change", Kennedy School of Government, January 2010, see https://www.belfercenter.org/sites/default/files/legacy/files/KeohaneVictor_Final.pdf, accessed 22 May 2018.

888 - IAEA, "PRIS—Country Details", see https://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=IR, accessed 15 May 2018.

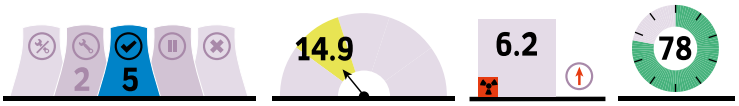
889 - *NIW*, "Iran", 3 November 2017.

890 - *NIW*, "Iran", 3 November 2017.

the late 1990s. It is still considered as "cancelled construction" (since 1978) by WNISR and will remain in this category until its official construction restarts.

Iran has been rapidly expanding its renewable energy capacity. The bulk of the capacity currently is hydropower, but, according to the International Renewable Energy Agency (IRENA), wind capacity has grown from 63 MW (2008) to 191 MW (2017) in the past decade, while solar energy capacity has jumped from 1 MW in 2013 to 111 MW in 2017.[891] Solar power is the main focus of renewable energy development in Iran. In October 2017, Iran signed a US$2.9 billion deal with Norway to build solar power plants.[892] The country reportedly has agreements with 124 companies, most of them European, to install 2.38 GW of new renewable capacity. However, the recent declaration by the U.S. to abrogate the Joint Comprehensive Plan of Action and reinstate sanctions could impede Iran's renewable development, by blocking investments by foreign energy firms.

Pakistan



Pakistan now operates five nuclear reactors with a combined capacity of 1.3 GW. In 2017, following the commissioning of a CNP-300 unit at Chasma (Chasnupp-4) in September 2017,[893] Pakistan's electricity production from nuclear energy was 8.1 TWh, which contributed 6.2 percent of the total electricity generated in the country. This contribution was an increase from 5.4 TWh and 4.4 percent in 2016, and may be attributed to the 2.5 TWh generated by Chasnupp-3 during 2017.

Construction of two HPR-1000 units (Kanupp-2 and -3) continued near Karachi, the most populous city in Pakistan with over 16 million inhabitants. The current projection is that these reactors will start operating in 2020 and 2021 respectively.[894] In November 2017, China National Nuclear Corporation (CNNC) and the Pakistan Atomic Energy Commission (PAEC) signed a cooperation agreement on the construction of an HPR-1000 Hualong One reactor at the Chasma nuclear power plant.[895] CNNC has "touted the agreement as another success in China's Belt and Road Initiative, Beijing's global infrastructure push".[896]

Although Pakistan predominantly relies on hydropower as well as imports of oil and gas as an energy source, there is ample scope to expand renewable energy. In recent years, the installed capacity of renewable energy has been growing relatively rapidly, with the current installed capacity of 1.5 GW.[897] The International Renewable Energy Agency (IRENA) estimates the

891 - IRENA, "Renewable Capacity Statistics 2018", Press Release, 5 April 2018, see http://www.irena.org/publications/2018/Mar/Renewable-Capacity-Statistics-2018, accessed 5 April 2018.

892 - Lefteris Karagiannopoulos, "In oil-producing Iran, renewables are booming", *Reuters*, 19 October 2017, see https://www.reuters.com/article/us-iran-renewables/in-oil-producing-iran-renewables-are-booming-idUSKBN1CO1CO, accessed 15 May 2018.

893 - WNISR, "Grid Connection of Chasnupp-4 in Pakistan", 6 July 2017, see https://www.worldnuclearreport.org/Grid-Connection-of-Chasnupp-4-in-Pakistan.html, accessed 11 May 2018.

894 - PNRA, "Nuclear Safety - Table-1: Nuclear Installations", Pakistan Nuclear Regulatory Authority, July 2018, see http://www.pnra.org/n-safety.html, accessed 28 July 2018.

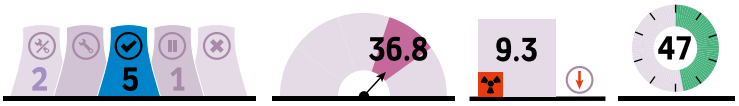
895 - *WNN*, "Pakistan, China agree to build Chashma 5", 23 November 2017, see http://www.world-nuclear-news.org/NN-Pakistan-China-agree-to-build-Chashma-5-2311177.html, accessed 4 May 2018.

896 - *NIW*, "Weekly Roundup", 27 November 2017.

897 - *Pakistan Observer* "'Pakistan all set to produce over 1,000MW of clean energy through wind power alone'", 22 April 2018, see https://pakobserver.net/pakistan-all-set-to-produce-over-1000mw-of-clean-energy-through-wind-power-alone/, accessed 11 May 2018.

potential for renewable energy in Pakistan to include 50 GW of wind energy alone, and substantial potential for solar energy generation all over the country, especially in the Baluchistan area.[898] The technical potential for solar energy has been estimated by Pakistan's Alternative Energy Development Board to be as much as 2,900 GW,[899] although much of this would likely not be economical. IRENA also "finds that several key challenges would need to be effectively addressed" for Pakistan to increase its intake of renewable energy.[900]

Taiwan



Taiwan has six reactor units at Chinshan (also spelled Jinshan), Kuosheng (Guosheng) and Maanshan, all owned by Taipower, the state-owned utility monopoly. Four of the reactors had long outages throughout 2017, thus a significant drop (29.2 percent) in power generation from 30.5 TWh in 2016 to 21.6 TWh in 2017, providing 9.3 percent of the country's electricity, compared with 13.5 percent in 2016,[901] and its maximum share of 41 percent in 1988. This is the first time since the buildup of the nuclear program in the late 1970s to mid-1980s that the share of nuclear power in the electricity mix dropped below 10 percent.

The government, which was elected in May 2016, is committed to a nuclear phase-out by 2025, while transitioning the energy economy to renewables. The plans for ending nuclear power progressed significantly during the past year with the approval of Taipower's decommissioning plan for the two units at Chinshan, and preparations for submission of the decommissioning plan for the two units at Kuosheng, with approval by the Atomic Energy Council (AEC) scheduled for December 2018.[902]

As in 2016, the Chinshan-1 reactor failed to operate during 2017, and therefore remains in the WNISR category of LTO. Originally shut down for refueling on 10 December 2014, inspections of Chinshan-1 revealed a break in a connecting bolt in an AREVA-made fuel assembly. The AEC later approved the reactor for restart, but lawmakers required the issue to be addressed by the national parliament prior to restart.[903] Both reactors at Chinshan are Mark 1 BWRs, which began operation in 1977 and 1978 respectively. In May 2016, environmental groups launched a court case against the restart of Chinshan-1 calling it the "most dangerous reactor in the world".[904]

As of 1 July 2018, Chinshan-1 remains in LTO. While the AEC is required to prepare a safety assessment for the legislative assembly prior to restart. Taipower's decommissioning plan for

898 - IRENA, "Renewables Readiness Assessment: Pakistan", International Renewable Energy Agency, 2018.

899 - *The Nation*, "500MW will be added to national grid soon: AEDB", 3 September 2012, see https://nation.com.pk/03-Sep-2012/500mw-will-be-added-to-national-grid-soon-aedb, accessed 11 May 2018.

900 - IRENA, "Renewable Energy Can Build Prosperity and Improve Energy Security in Pakistan", 10 April 2018, see http://www.irena.org/newsroom/pressreleases/2018/Apr/Pakistan-RRA, accessed 4 May 2018.

901 - Taipower, "Current Status and Prospects of Chinshan and Kuosheng Nuclear Power Plant Decommissioning Programs", September 2017.

902 - Taipower, "Current Status and Prospects of Chinshan and Kuosheng Nuclear Power Plant Decommissioning Programs", 2017.

903 - *NW*, "Chinshan-1 might not restart until after September: lawmakers", 2 July 2015

904 - Chen Wei-han, "Activists file suit over Jinshan reactor", *Taipei Times*, 31 May 2016, see http://www.taipeitimes.com/News/taiwan/archives/2016/05/31/2003647555, accessed 9 July 2018.

both units at Chinshan were approved by the AEC in June 2017.[905] Following several years of efforts, it is now a near certainty that Chinshan-1 will not restart before its permanent shutdown on 5 December 2018. [906]

On 2 June 2017, Chinshan-2 had automatically shut down after one of the main transmission line towers at the plant collapsed during a heavy rainstorm.[907] Taipower stated that the reactor will remain offline indefinitely until an investigation reveals more details about the cause of the collapse. The reactor was scheduled to be shut down on 10 June 2017 due to lack of spent fuel storage capacity. Dry cask storage capacity has been constructed at Chinshan (and Kuosheng) and approved by the AEC and the Environmental Protection Administration, but the New Taipei City government has refused to let them become operational, without which it is not possible to make space for unloading the current fuel load in the reactor.[908] Chinshan-2, as of 1 July 2018, remains shut down. The reactor is scheduled for permanent closure on 15 July 2019, and it looks doubtful that it will restart operation.

On 5 March 2018, the AEC approved the safety case for restart of Kuosheng-2, which had been shut down since May 2016.[909] The reactor was connected to the grid shortly after.

Table 15 | Dates of Permanent Cessation of Operation of Nuclear Reactors in Taiwan

Reactor	Type	Capacity MW	Grid Connection (dd/mm/yyyy)	Date of Cessation of Operation (dd/mm/yyyy)
Chinshan-1	BWR	604	16/11/1977	05/12/ 2018
Chinshan-2	BWR	604	19/12/1978	15/07/2019
Kuosheng-1	BWR	951	21/05/1981	27/12/ 2021
Kuosheng-2	BWR	951	29/06/1982	14/03/ 2023
Maanshan-1	PWR	890	09/05/1984	26/07/ 2024
Maanshan-2	PWR	890	25/02/1985	17/05/ 2025

Sources: Taipower, "Current Status and Prospects of Chinshan and Kuosheng Nuclear Power Plant", 2017 Decommissioning Programs", September 2017[910]

Two General Electric (GE) 1300 MW Advanced Boiling Water Reactors (ABWR) had been listed as "under construction" at Lungmen, near Taipei, since 1998 and 1999 respectively. According to the AEC, as of the end of March 2014, Lungmen-1 was 97.7 percent complete,[911] while unit 2

905 - Chen Wei-han, "Activists file suit over Jinshan reactor", *Taipei Times*, 31 May 2016.

906 - AEC, "NPP Real-time Operating Status", Updated 1 July 2018, see https://www.aec.gov.tw/english/nuclear/index11.php, accessed 2 July 2018.

907 - Kuan-lin Liu, "Emergency shutdown at nuke plant after rain brings down power tower", *The China Post*, 2 June 2017, see http://www.chinapost.com.tw/taiwan/national/national-news/2017/06/02/498234/emergency-shutdown.htm, accessed 9 July 2018.

908 - *Taiwan Business*, "More Obstacles for Nuclear Power", 6 June 2017, see https://topics.amcham.com.tw/2017/06/obstacles-nuclear-power/, accessed 9 July 2018; and AEC, "NPP Real-time Operating Status", 1 July 2018, see https://www.aec.gov.tw/english/nuclear/index11.php, accessed 2 July 2018.

909 - *NEI*, "Taiwan regulator approves restart of Kuosheng 2", 12 March 2018, see http://www.neimagazine.com/news/newstaiwan-regulator-approves-restart-of-kuosheng-2-6079399, accessed 2 June 2018.

910 - Taiwan Power Company, "Current Status and Prospects of Chinshan and Kuosheng Nuclear Power Plant Decommissioning Programs", TaiPower, September 2017, see http://www.cieca.org.tw/v_comm/inc/download_file.asp?re_id=2998&fid=35220, accessed 15 August 2018.

911 - Planning Department, "Status and Challenges of Nuclear Power in Taiwan", AEC, April 2014, see http://www.aec.gov.tw/english/whatsnew/files/20140506-5.pdf, accessed 9 July 2018.

was 91 percent complete. The plant is estimated to have cost US$9– 9.9 billion so far.[912] After multiple delays, rising costs, and large-scale public and political opposition, including local referendums, on 28 April 2014, the then Premier, Jiang Yi-huah, announced that Lungmen-1 will be mothballed after the completion of safety checks, while work on unit 2 at the site was to stop. The Democratic Progressive Party (DPP) government was elected with a pledge to halt construction of the Lungmen plant, and with a nuclear phase out planned for 2025, there are little prospects that they will ever operate. A formal decision on terminating the project would potentially force Taipower to file for bankruptcy as the listing of Lungmen as an investment asset would switch to company loss.[913] With the official freeze of construction, WNISR took the units off the listing in 2014, where they remain as of 1 July 2018. The IAEA continues to list the reactors as under construction.[914]

Units 1 and 2 at Kuosheng are set for permanent closure in December 2021 and March 2023, followed by the two reactors at the Maanshan in Pingtung County in July 2024 and May 2025 (see Table 15).

Energy Transition and Renewables Investment

Historical public opposition to nuclear power in Taiwan, dramatically escalated during and in the months following the start of the Fukushima Daiichi accident, has been a principal driver of the nation's ambitious plans for a renewable energy transition. One consequence of the March 2011 disaster was a new government policy by the ruling Chinese Nationalist Party (Kuomintang, KMT) party in November 2011 which determined that there would be no life extension of reactors beyond 40 years. But it was the election of Democratic Progressive Party (DPP) into government in May 2016 on a platform of phasing out nuclear power, that has triggered the energy transition. The "New Energy Policy Vision", announced by the administration of President Tsai 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.[915] 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.[916] The law also gives priority to the distribution of renewable energy, by which its generators will be given 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.[917]

912 - *WNN*, "Political discord places Lungmen on hold", 28 April 2014, see http://www.world-nuclear-news.org/NN-Political-discord-places-Lungmen-on-hold-2804144.html, accessed 9 July 2018.

913 - *Taipei Times*, "NUCLEAR POWER DEBATE: Scrapping plant would ruin Taipower: Duh", 28 April 2014, see http://www.taipeitimes.com/News/taiwan/archives/2014/04/29/2003589160, accessed 2 June 2018.

914 - IAEA, "Taiwan, China", PRIS, as of 1 July 2018, see https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=TW, accessed 1 July 208.

915 - 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 July 2018.

916 - Bureau of Energy, "The Three-Stage Reading Process for Electricity Act Amendment Completed Moving Towards the 2025 Target of Nuclear-Free Homeland", MOEA, 1 March 2017, see http://web3.moeaboe.gov.tw/ECW/english/news/News.aspx?kind=6&menu_id=958&news_id=5628, accessed 9 July 2018.

917 - *The China Post*, "Lawmakers OK wide-ranging amendments to Electricity Act", 12 January 2017, see https://chinapost.nownews.com/20170112-14213, accessed 9 July 2018.

The past year has seen multiple policy measures and developments that will likely see dramatic renewables expansion,[918] with Taiwan considered to be leading the way for Asian expansion of offshore wind, not least due to the potential in the Taiwan Strait.[919] In May 2018, Taiwan's Ministry of Economic Affairs announced that it had awarded seven companies to build 10 offshore wind farms worth a total of 3.8 GW by 2025.[920] Overall renewable targets for 2025 are 25 GW. Asia Pacific Director for Mitsubishi Heavy Industries (MHI)/ Vestas Offshore Wind (MVOW) identified the business opportunities in Taiwan:

1) The political will to move towards renewable energy with clear offshore wind targets,
2) good wind conditions that allow offshore wind to compete on cost,
3) good market design with a feed-in tariff that attracts new market entrants and has ample volume, and
4) supporting infrastructure build-out program including grid connections.[921]

One reason for the interest of overseas investment is that Taiwan currently has a feed-in-tariff for offshore wind of US$199/MWh fixed for 20 years, compared with current European auction price ranging from US$40-75/MWh.[922]

> *"multiple policy measures and developments that will likely see dramatic renewables expansion"*

Taiwan's energy transition also aims to reduce coal generating capacity from the current 45 to 30 percent and increasing LNG electricity generation from 32 to 50 percent. The government aims to attract NT$1.8 trillion (US$59 billion) of private capital investment in renewable energy through 2025, without which attaining the 25 percent renewables share is predicted by *Bloomberg* will fall short.[923]

The challenge of shutting nuclear power plants, when the energy transition has only begun, was highlighted in the 2017 summer heat wave, when power shortages dominated news reporting, coinciding with multiple reactor outages, and typhoon damage to major transmission structure, which reduced reserve margins to below 2 percent of electrical capacity. The tight margins led some business leaders to call for a rethink on the nuclear phaseout plan, including extending the lifetimes of Chinshan reactors due to shut down in 2018 and 2019. The government restated that it will not consider restarting Chinshan-1 unless all other alternatives had been exhausted.[924]

918 - RMI, "Taiwan Makes It Easier for Global Companies to Procure Local Renewable Energy", 21 March 2017, see https://rmi.org/news/taiwan-makes-easier-global-companies-procure-local-renewable-energy/, accessed 2 June 2018.

919 - *Bloomberg*, "'Dawn' of Asia Offshore Wind Boom Lures Japanese Trading Houses", 29 May 2018, see https://www.bloomberg.com/news/articles/2018-05-28/-dawn-of-asia-offshore-wind-boom-lures-japanese-trading-houses, accessed 2 June 2018.

920 - *Offshore Wind Journal*, "Taiwan makes good on plan to replace nuclear power with wind", 10 May 2018, see http://www.owjonline.com/news/view,taiwan-makes-good-on-plan-to-replace-nuclear-power-with-wind_51748.htm, accessed 2 June 2018.

921 - *CleanTechnica*, "Taiwan Emerges As Offshore Wind's Next Power Base With 3.8 Gigawatt Tender", 27 May 2018, see https://cleantechnica.com/2018/05/27/taiwan-emerges-as-offshore-winds-next-power-base-with-3-8-gigawatt-tender/, accessed 2 June 2018.

922 - RMI, "Taiwan Makes It Easier for Global Companies to Procure Local Renewable Energy, 2017.

923 - Miaojung Lin, Lianting Tu "Taiwan Lays Plans for $59 Billion in Renewable-Energy Finance", *Bloomberg*, *19 June 2017, see* https://www.bloomberg.com/news/articles/2017-06-18/taiwan-lays-plans-for-59-billion-in-renewable-energy-finance, accessed 2 June 2018.

924 - Evelyn Kao, "Tight power supply revives discussion on nuclear energy in Taiwan", *Focus Taiwan*, 14 August 2017, see http://focustaiwan.tw/news/aftr/201708140020.aspx, accessed 3 June 2018.

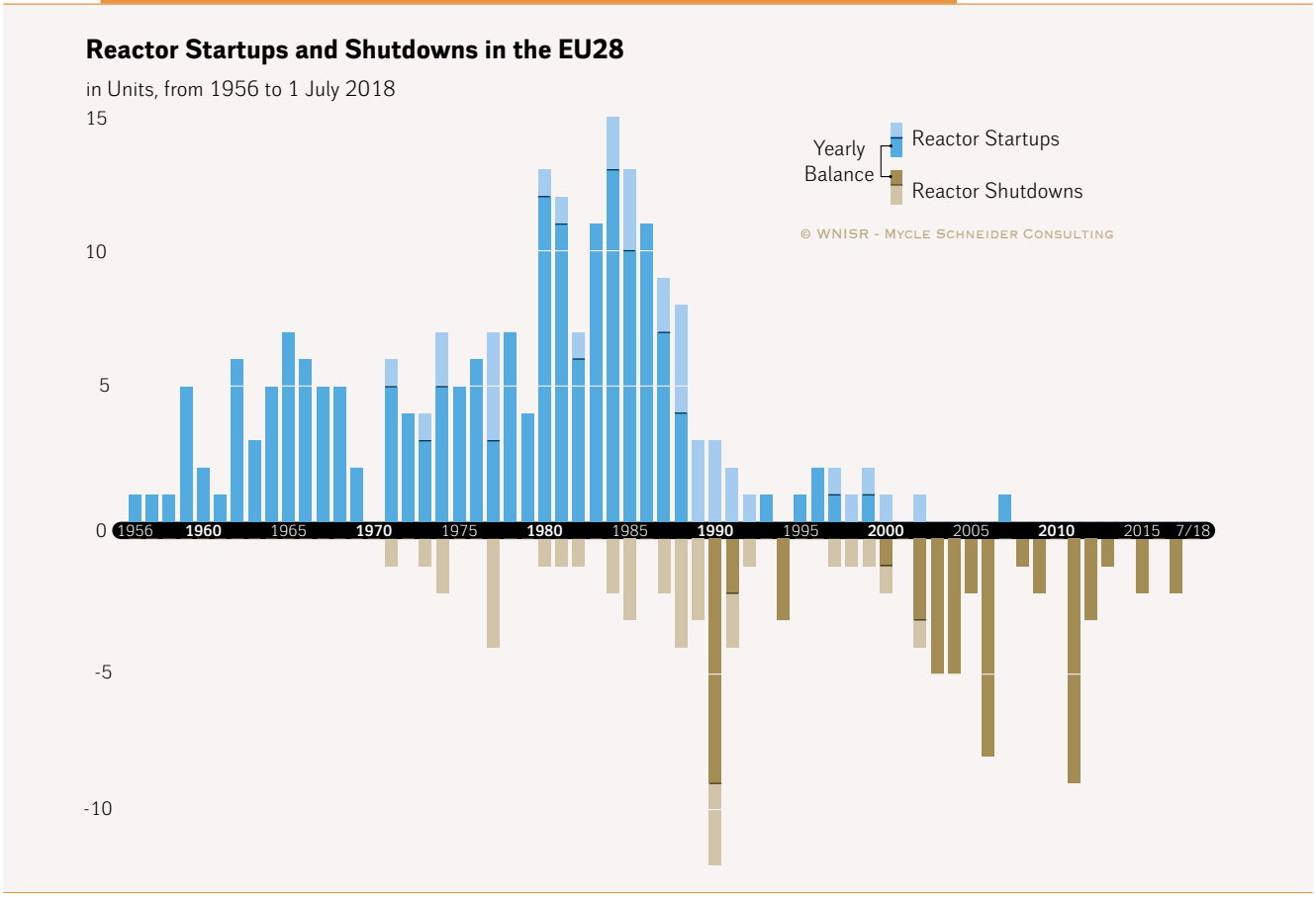
EUROPEAN UNION (EU28)

As illustrated in Figure 46, the 28 member states of the European Union (EU28) have gone through three nuclear construction waves—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 building activity since the 1990s. There were no construction starts in Western Europe since 1991, prior to Olkiluoto-3 (2005) and Flamanville-3 (2007), and none after. Only five reactors were connected to the EU-grid over the past 20 years, four in Eastern Europe (two in Slovakia and one each in Romania and Czech Republic) and one in France, none since Cernavoda-2 started up in 2007.

One reactor was closed in the EU since WNISR2017. Gundremmingen-B in Germany was shut down on 31 December 2017 as part of the national nuclear phase-out plan. This brings the total number of permanently shut down units to 94 in the European Union.

Figure 46 | Nuclear Reactors Startups and Shutdowns in the EU28, 1956–1 July 2018



Sources: WNISR, IAEA-PRIS, 2018

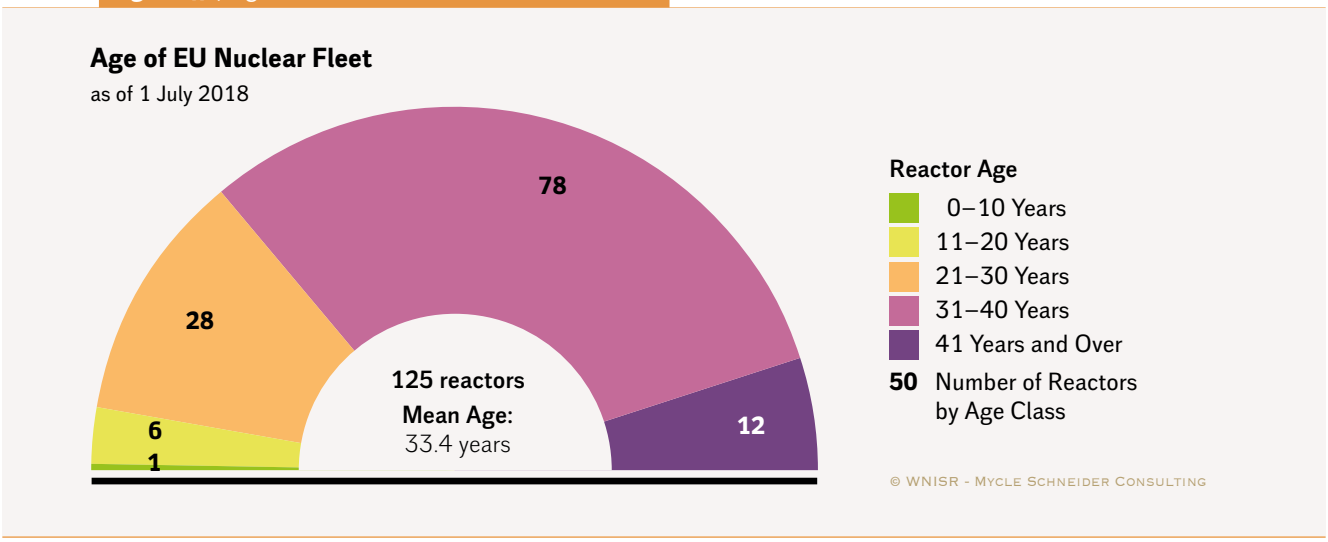
Just as one year earlier, as of 1 July 2018, the 28 countries in the enlarged EU operated 125 reactors—about one-third of the world total—52 less than the historic maximum of 177 units in 1989 (see Figure 48).

The French reactor Bugey-5 was restarted in July 2017 after almost two years of repair work and therefore moved from LTO back to the in-operation category. The French Paluel-2 reactor remains in LTO, as it has not provided any power since May 2015 (see Focus France for details).

The vast majority of the operating facilities, 106 units or over 80 percent, are located in eight of the western countries, and only 19 are in the six newer member states with nuclear power.

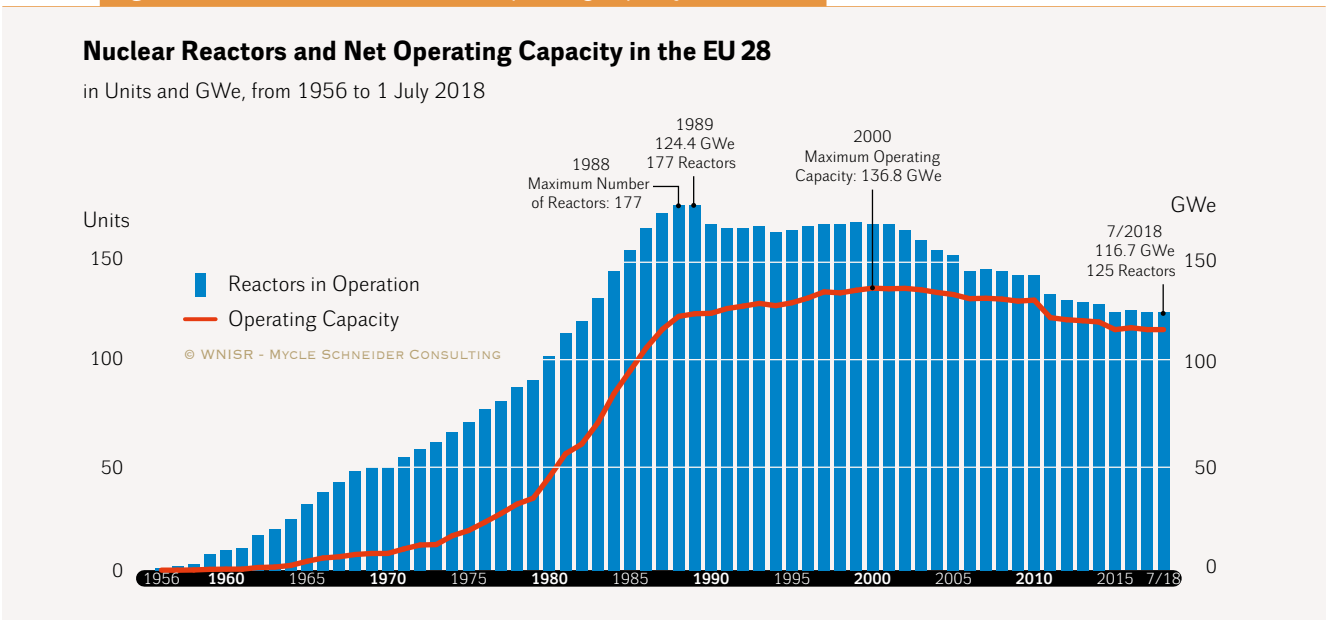
In the absence of any successful new-build program, the average age of nuclear power plants is increasing continuously in the EU and at mid-2018 stands at 33.4 years (see Figure 47). The age distribution shows that now 72 percent—90 of 125—of the EU's operating nuclear reactors have been in operation for 31 years and beyond.

Figure 47 | Age Distribution of the EU28 Reactor Fleet



Sources: WNISR, IAEA-PRIS, 2017

Figure 48 | Nuclear Reactors and Net Operating Capacity in the EU28



Sources: WNISR, IAEA-PRIS, 2018

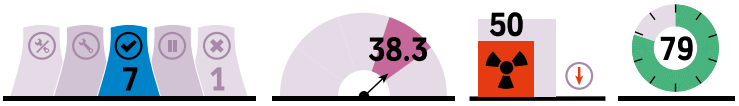
WESTERN EUROPE

As of 1 July 2018, just as one year earlier, 106 nuclear power reactors operated in the EU15, 51 units fewer than in the peak years of 1988/89. As stated above, Bugey-5 in France restarted generating power and was thus moved from the Long-Term Outage (LTO)- to the operating-category. Paluel-2, also in France, remains in the LTO category.

Two reactors are currently under construction in the older member states, one in Finland (Olkiluoto-3) and one in France (Flamanville-3). Both projects are many years behind schedule and billions over budget (details are discussed in other chapters of the report). While the "Final Investment Decision" for EDF Energy's Hinkley Point C project in U.K. has finally been taken in the fall of 2016, construction is not scheduled to start before 2019.

The following section provides a short overview by country (in alphabetical order).

Belgium



Belgium operates seven pressurized-water reactors that have generated 40.19 TWh in 2017, vs. 41.43 TWh in 2016 (maximum of 46.7 TWh in 1999) corresponding to 49.5 percent of the electricity (the maximum was 67.2 percent in 1986. The average load factor of the Belgian fleet remains remarkably high at 79.2 percent in 2016-17, in spite of a series of technical problems (see below). The average age of the Belgian fleet is 38.3 years.

Legally, the country is bound to a nuclear phase-out target of 2025. In January 2003, legislation was passed that requires the shutdown of all of Belgium's nuclear plants after 40 years, so based on their start-up dates, plants would be shut down progressively between 2015 and 2025 (see Table 16). 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 exist in 2025".[925] However, the Belgian government confirmed the nuclear phase-out date, when, on 30 March 2018, it presented the Federal Energy Strategy. Various legal initiatives will accompany a package of climate and energy policy measures over the coming months.[926]

Following Fukushima, the phase-out legislation was left in place even though GDF-Suez (now Engie), that operates all seven PWRs through its subsidiary Electrabel, was lobbying to postpone it via an extension of "at least 10 years".[927] In December 2013, the phase-out legislation

925 - Elia Group, "Elia publishes study with electricity scenarios for Belgian energy system towards 2050 and calls for rapid action to ensure a reliable, affordable and sustainable electricity system", 15 November 2017.

926 - Prime Minister's Office, "Strategie energetique federale.pdf", Belgian Federal Government, 30 March 2018, see https://premier.fgov.be/sites/default/files/articles/Strategie%20energetique%20federale.pdf, accessed 14 July 2018.

927 - Gérard Mestrallet, et al., "Nuclear in Belgium: recent developments", GDF Suez, 4 November 2011.

was amended for the first time,[928] granting a 10-year extension for the Tihange-1 reactor.[929] The other shutdown dates were confirmed (see Table 17) and the law's Article 9, which enabled continued operation in case of security-of-supply concerns, was deleted.

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 respectively—previously undetected defects.[930] In spite of widespread concerns, and although no accountable explanation about the negative initial fracture toughness test results was given, on 17 November 2015, Federal Agency for Nuclear Control (FANC) authorized restart of Doel-3 and Tihange-2[931] for the second time after the original discovery of defaults. (see previous WNISR editions for details).

Table 16 | Closure Dates for Belgian Nuclear Reactors 2022–2025

Reactor (Net Capacity)	First Grid Connection	End of License (Latest Closure Date)
Doel-3 (1006 MW)	1982	1 October 2022
Tihange-2 (1008 MW)	1982	1 February 2023
Doel-1 (433 MW)	1974	10-year lifetime extension to 15 February 2025
Doel-4 (1039 MW)	1985	1 July 2025
Tihange-3 (1046 MW)	1985	1 September 2025
Tihange-1 (962 MW)	1975	10-year lifetime extension to 1 October 2025
Doel-2 (433 MW)	1975	10-year lifetime extension to 1 December 2025

Sources: Belgian Law of 28 June 2015; Electrabel/GDF-Suez, 2015[932]

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

928 - Moniteur Belge, "18 Décembre 2013—Loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l'énergie nucléaire à des fins de production industrielle d'électricité et modifiant la loi du 11 avril 2003 sur les provisions constituées pour le démantèlement des centrales nucléaires et pour la gestion des matières fissiles irradiées dans ces centrales", 24 December 2013.

929 - Melchior Wathelet, "Avec la réserve stratégique, Melchior Wathelet finalise l'exécution de son plan", Energy Minister, Belgian Federal Government, 16 December 2013.

930 - FANC, "Doel 3/Tihange 2: clarifications regarding the detection, the position and the size of the flaw indications", 25 February 2015, see http://www.fanc.fgov.be/fr/news/doel-3/tihange-2-clarifications-regarding-the-detection-the-position-and-the-size-of-the-flaw-indications/753.aspx, accessed 2 July 2016.

931 - Engie/Electrabel, "The Federal Agency for Nuclear Control approves safe restart of Doel 3 and Tihange 2", Press Release, 17 November 2015, see http://corporate.engie-electrabel.be/news/press-releases/the-federal-agency-for-nuclear-control-approves-safe-restart-of-doel-3-and-tihange-2/, accessed 2 July 2016.

932 - 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", Press Release,1 December 2015, (in French), see corporate.engie-electrabel.be/wp-content/uploads/2016/03/note-de-presse-prolongation-doel-1-et-doel-2-securite-dapprovisionnement-en-belgique-fr-def.pdf, and "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 9 August 2017.

to 2025.[933] The law went into effect on 6 July 2015.[934] The government signed an agreement with Electrabel on 30 November

2015 that stipulates that the operator will invest €700 million (US$741.2 million) into upgrading of the two units[935] and an annual fee of €20 million (US$21.2 million), which will be paid into the national Energy Transition Fund, set up by the law of 28 June 2015. On 22 December 2015, FANC authorized the lifetime extension and restart of Doel-1 and -2.

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 addresses a series of questions to the European Court of Justice, in particular concerning the interpretation of the Espoo and Aarhus Conventions, as well as the European legislation.[936] Already in November 2015, Greenpeace Belgium had filed a case at the State Council (Conseil d'État) on similar grounds.[937] As of mid-2018, both cases are still pending.

In May 2017, FANC announced that a series of ultra-sonic inspections on the pressure vessel of Tihange-2 did not show any evolution of the hydrogen flakes, nor any new defects. On the basis of these results, FANC authorized the restart of the reactor.[938] FANC later admitted that over 300 additional flaw indications at Doel-3 and 70 additional flaw indications at Tihange-2 exceeded the recording threshold for the first time during re-inspections carried out in 2016 and 2017 respectively. However, FANC concluded that the results were due to evolving complex inspection techniques rather than physical changes.[939]

> *"anomalies at the reinforcements of the reinforced concrete [were] present since the construction of the building"*

A complaint filed at the Belgian State Council against the restart of Tihange-2 by the City Region (Städteregion) Aachen cities in February 2016 [940] joined by some 80 other Dutch, German and Luxemburg cities, is also still pending.

In October 2017, Electrabel has identified serious flaws in the concrete of a building adjacent to the reactor buildings of Doel-3. According to Engie Electrabel, some of these "anomalies at the reinforcements of the reinforced concrete [were] present since the construction of the building".[941] These bunkered buildings contain backup systems relevant for the safety of the

933 - Marie-Christine Marghem, "Measures which intend to assure the security of supply in Belgium", Minister of Energy, Environment and Sustainable Development, Belgian Federal Government, Press Release, 5 March 2015, see http://www.marghem.belgium.be/en/measures-which-intend-assure-security-supply-belgium, accessed 2 July 2016.

934 - Moniteur Belge, op.cit.

935 - Electrabel, "Sécurité d'approvisionnement et transition énergétique—Accord sur la prolongation de Doel 1 et Doel 2", Press Release, 1 December 2015.

936 - Cour Constitutionnelle, "Arrêt N°82/2017", 22 June 2017.

937 - Johan Verstraeten, Atorny, "Verzoekschrift tot Schorsing en Nietigverklaring", Greenpeace Belgium, 29 November 2015.

938 - FANC, "Pas d'évolution des flocons d'hydrogène à Tihange", 5 May 2017, (in French), see http://www.fanc.fgov.be/fr/news/pas-d-evolution-des-flocons-d-hydrogenea-tihange-2/878.aspx, accessed 3 August 2017.

939 - FANC, "Doel 3 & Tihange 2: flaw indications in the reactor pressure vessel steel", Updated 8 June 2017, (in French and Dutch), see http://afcn.fgov.be/fr/page/doel-3-tihange-2-flaw-indications-in-the-reactor-pressure-vessel-steel/1989.aspx, accessed 3 August 2017.

940 - Tim Vermeir, Tinne Van der Straeten, "Verzoekschrift tot nietigverklaring", Städteregion Aachen, 5 February 2016.

941 - 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.

facilities and are supposed to withstand impact from outside like an airplane crash. Similar problems, but to a lesser degree, have been identified at Tihange-3. It remains unclear, what the consequences for the future operation of the reactors will be. Engie has already announced that Tihange-3, originally shut down on 30 March 2018 for planned maintenance and refueling, will not generate power at least until 30 September 2018. Restart is subject to authorization of FANC. In addition, Doel-1 and -2 are undergoing major upgrading work and will be off-line until at least 1 and 8 October 2018 respectively. Doel-3 will not restart until 1 August 2018, and Doel-4 has a revision scheduled from 6 August to 15 December 2018. The revised outage times added the equivalent of more than seven non-operating months in 2018 leading to an estimated €250 million shortfall in income, according to Engie.[942]

On 7 June 2018, the European Commission has decided to send a reasoned opinion to Belgium "for not having notified transposition measures required under the Nuclear Safety Directive (Council Directive 2014/87/Euratom)". Belgium is given two months' time to reply to the reasoned opinion, as well as to adopt and communicate all the necessary measures to ensure full and correct transposition of the Directive, "failing which the Commission may refer the case to the Court of Justice of the EU".[943]

In February 2018, the National Radioactive Waste Management Agency ONDRAF issued an update to an earlier back-end cost estimate that turned out 25 percent higher, increasing from €12.1 billion (US$14.8 billion) to €15.1 billion (US$18.5 billion). About half of the increase is due to the augmented decommissioning cost estimates for the country's seven reactors. Significant other factors contributing to the increase are the larger amount of spent fuel and waste to deal with due to lifetime extensions and the discounting rate of 4.2 percent imposed by the National Commission for Nuclear Provisions.[944]

Meanwhile, "Engie wants to exit nuclear power", as *BFM Business* headlined a December-2016 story on the Electrabel owner.[945] The operator of the Belgian nuclear fleet has sold its stakes in U.K. new-build projects, tries to get out of a Turkish new-build project and would like to sell Electrabel. There are indications that Engie considers another option, which is to empty Electrabel of most of its international and renewable energy assets and create a "bad bank" with the remaining nuclear plants, which soon will turn into liabilities of still uncertain dimensions.[946]

942 - ENGIE, "Financial information: update of the agenda of the scheduled revisions of three Belgian nuclear units", 18 June 2018, see https://www.engie.com/en/journalists/press-releases/the-scheduled-revisions-belgian-nuclear-units/, accessed 18 June 2018.

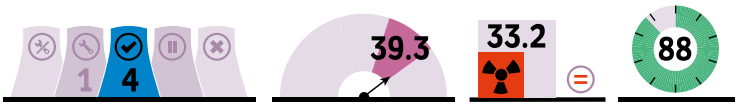
943 - Commission Européenne, "Press Release - June infringements package: key decisions", 7 June 2018, see http://europa.eu/rapid/press-release_MEMO-18-3986_en.htm, accessed 14 June 2018.

944 - ONDRAF, "Synthèse du quatrième rapport d'inventaire des passifs nucléaires de l'ONDRAF as sa tutelle (période 2013-2017)", Belgian National Radioactive Waste Management Agency, February 2018.

945 - Matthieu Pechberty, "Engie veut sortir du nucléaire", *BFM Business*, 7 December 2016, (in French), see http://bfmbusiness.bfmtv.com/entreprise/engie-veut-sortir-du-nucleaire-1067637.html, accessed 3 August 2017.

946 - Christine Scharff, "Engie confirme analyser plusieurs options pour ses activités belges", *L'Echo*, 18 May 2018, see https://www.lecho.be/entreprises/energie/engie-confirme-analyser-plusieurs-options-pour-ses-activites-belges/10012957.html, accessed 21 May 2018.

Finland



Finland operates four units that in 2017 supplied 21.58 TWh, compared to 22.28 TWh in 2016, close to the 2013 record of 22.67 TWh. The nuclear share remained stable at 33.2 percent of electricity production (with a maximum of 38.4 percent in 1986). Finland has adopted different nuclear technologies and suppliers, as two of its operating reactors are PWRs built by Russian contractors at Loviisa, while two are BWRs built by ABB (Asea Brown Boveri) at Olkiluoto. The average age of the four operating reactors is 39.3 years. In January 2017, operator Teollisuuden Voima's (TVO) filed an application for a 20-year license extension for the respectively 39- and 37-year old units Olkiluoto-1 and -2.[947]

On 1 June 2018, the Finnish, Radiation and Nuclear Safety Authority (STUK) approved of the life extension of the operating license for Teollisuuden Voima's (TVO) Olkiluoto-1 and -2.[948] The current operating license of both units is apparently still due to expire at the end of 2018, pending a license renewal procedure by the government, that involves gathering opinions from various ministries, other authorities and municipalities. [949]

In December 2003, Finland became the first country to order a new nuclear reactor in Western Europe in 15 years. AREVA NP, then a joint venture owned 66 percent by AREVA and 34 percent by Siemens,[950] is building a 1.6 GW EPR at Olkiluoto (OL3) under a fixed-price turn-key contract with the utility TVO. After the 2015 technical bankruptcy of AREVA Group, in which the cost overruns of Olkiluoto had played a major 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 repeatedly that it will not take over the billions of euros' liabilities linked to the costly Finnish AREVA adventure.[951] 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$2.3 billion) capital increase, most of which was to cover the costs to AREVA of the OL3 project.[952]

The OL3 project was financed essentially on the balance sheets of the Finland's leading firms and 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

947 - TVO, "New operating license applied for Olkiluoto 1 and 2 plant units", 26 January 2017, see http://tvo.fi/news/1830, accessed 8 July 2018.

948 - STUK, "Operation of Olkiluoto 1 and 2 can be continued safely", 1 June 2018, see http://www.stuk.fi/web/en/-/operation-of-olkiluoto-1-and-2-can-be-continued-safely, accessed 9 July 2018.

949 - Ministry of Economic Affairs and Employment, "Olkiluoto 1 and 2 operating licence", as of 17 June 2018, see https://tem.fi/en/olkiluoto-1-and-2-operating-licence, accessed 17 June 2018.

950 - Siemens quit the consortium in March 2011 and announced in September 2011 that it was abandoning the nuclear sector entirely, *WNN*, "Siemens quits the nuclear game", 19 September 2011, see http://www.world-nuclear-news.org/C_Siemens_quits_the_nuclear_game_1909111.html, accessed 4 June 2018.

951 - Jean-Michel Bezat, "EDF pose ses conditions au rachat des réacteurs d'Areva", *Le Monde*, 19 May 2015, (in French), see http://www.lemonde.fr/economie/article/2015/05/19/edf-pose-ses-conditions-au-rachat-des-reacteurs-d-areva_4636164_3234.html, accessed 9 July 2018.

952 - Jean-Michel Belot, Richard Lough "Areva says French state completes two billion-euro capital increase", *Reuters*, 13 July 2017, see https://www.reuters.com/article/us-arevasa-capital-idUSKBN19X2S9, accessed 4 June 2018.

"take-or-pay contract", in addition to the additional billions incurred by AREVA under the fixed price contract.

OL3 construction started in August 2005 at Olkiluoto on the west coast, with operations planned from 2009. However, as that date—and other dates—passed, in its 2015 Annual Report, TVO stated: "According to the schedule updated by the Supplier, regular electricity production at OL3 will commence at the end of 2018".[953] It will not happen neither.

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 55 nationalities made communication and oversight extremely complex (see previous WNISR editions).

After further multiple delays, TVO announced in October 2017 that it had again delayed planned commercial operation from November 2018, to May 2019, with grid connection planned for December 2018.[954] "We are very disappointed by this additional delay... There is still substantial work to be accomplished", Jouni Silvennoinen, TVO's senior vice president for the OL3 project, said in a statement.[955] A further delay was announced in June 2018. Grid connection is now expected in May 2019, and "regular electricity generation" in September 2019.[956]

Predicted nearly a decade ago as a project that would lead to a crisis,[957] OL3 was cited by the industry as a showcase for next-generation EPR-reactor technology with TVO and AREVA predicting 56 months to completion. In reality, its total construction time to operation on the current schedule will be 163 months, and operation ten years behind schedule. TVO announced in April 2018 that fuel loading was delayed until autumn 2018, (prior to this it had been scheduled for April 2018).[958] On 30 May 2018, five months of hot functional testing of the reactor, designed to verify safety cooling systems and operability of the plant were completed.[959] TVO, as of 1 July 2018, was awaiting a safety assessment from STUK, to be followed by the Government approving the license to operate.

One of the consequences of the escalating costs and delays is that the principle partners in the project, TVO and AREVA openly fought over financial liability. In February 2016, AREVA updated its claim against TVO to €3.4 billion (US$3.7 billion), while TVO had increased its own compensation claim against AREVA to €2.6 billion (US$2.85 billion) in August 2015.[960] As of

953 - TVO, "Report of the Board of Directors and Financial Statements 2015", February 2016, see http://www.tvo.fi/news/1692, accessed 9 July 2018.

954 - Jussi Rosendahl, Tuomas Forsell, "Areva's Finland reactor to start in 2019 after another delay", *Reuters*, 9 October 2017, see https://www.reuters.com/article/us-finland-nuclear-olkiluoto/arevas-finland-reactor-to-start-in-2019-after-another-delay-idUSKBN1CE1ND, accessed 4 June 2018.

955 - Ibidem.

956 - TVO, "OL3 EPR's regular electricity generation starts in September 2019" (Press Release), 13 June 2018, see https://www.tvo.fi/news/2000, accessed 13 June 2018.

957 - Steve Thomas, "The EPR in Crisis", PSIRU Business School, University of Greenwich, London, November 2010, see http://gala.gre.ac.uk/4699/3/%28ITEM_4699%29_THOMAS_2010-11-E-EPR.pdf, accessed 4 June 2018; and WNISR, "The World Nuclear Industry Status Report 2009", see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-52.html, accessed 4 June 2018.

958 - AREVA, "2016 Reference Document", May 2017.

959 - TVO, "Hot functional tests completed successfully at OL3", 30 May 2018, see https://www.tvo.fi/news/1994, accessed 4 June 2018.

960 - *NW*, "Talks with TVO on Olkiluoto-3 'positive' and 'fast paced,' Areva CEO says", 3 March 2016.

the end of 2016, TVO compensation claims amount to about €2.3 billion (US$2.4 billion), while AREVA-Siemens in return claimed €3.5 billion (US$3.7 billion).

In March 2018, the parties announced that they had reached agreement on the completion of OL3, including all related disputes.[961] In relation to costs and losses caused by the delays, financial compensation of €450 million was to be paid by AREVA to TVO in two instalments. There was also a commitment by AREVA that there were sufficient funds for completion of OL3 and that they will cover all applicable guarantee periods, including setting up a trust mechanism funded by AREVA to secure the financing of the costs of completion of the project. The settlement agreement also agreed that in the event that AREVA fails to complete the project by the end of 2019, they will pay a penalty to TVO that may not exceed €400 million. The agreement also notes the plant supplier's most recent schedule according to which regular electricity production in the unit will commence in May 2019.

With the confirmation of the settlement, and TVO disclosing its total investment, it is possible to indicate the cost of the Finnish EPR. TVO's current capital expenditure assumptions and the effect of the settlement agreement, estimates its total investment to be around €5.5 billion (US$6.42 billion), on top of this AREVA had losses of €5.5 billion, for a total of €11 billion (US$12.4 billion), compared with the initial estimate cost in 2003 of "around €3 billion".

Separately, the International Chamber of Commerce (ICC) arbitration process, which had been considering liability over OL3, issued a partial ruling in TVO's favor in July 2017.[962] With the settlement agreement in March 2018, all parties announced their withdrawal from ICC proceedings.

In December 2017, STUK concluded an investigation into the safety implications of the use of suspect steel components supplied by Le Creusot and SBS factories in France to OL3. Based on a report from TVO and STUK investigators, they confirmed that the investigation into OL3 is now complete, with the determination that the quality of materials was confirmed with "sufficient certainty."[963]

In March 2018, the International Atomic Energy Agency (IAEA) announced the completion of its Pre-Operational Safety Review Team (OSART) of OL3. Noting that after 13 years of construction, "the plant has developed and implemented an efficient system for improving knowledge and skills of staff members," while also recommending that "plant management should set appropriate expectations, communicate them to staff and reinforce them in the field."[964]

One consequence of the escalating costs of OL3 was in 2015, when credit-rating agency Standard & Poor's (S&P) downgraded TVO to BBB-, with a negative outlook, "owing to conti-

961 - TVO, "TVO confirms a settlement agreement signed on OL3 EPR project completion and related disputes", 11 March 2018, see https://www.tvo.fi/news/1966, accessed 4 June 2018.

962 - AREVA, "OL3 PROJECT: The International Chamber Of Commerce Makes A Partial Ruling On Arbitration", Press Release, 20 July 2017, see http://www.sa.areva.com/EN/news-10986/ol3-project-the-international-chamber-of-commerce-makes-a-partial-ruling-on-arbitration.html, accessed 4 June 2018.

963 - STUK, "Investigation of suspected counterfeit products at Olkiluoto 3 completed", Press Release, 19 December 2018, see http://www.stuk.fi/web/en/-/investigation-of-suspected-counterfeit-products-at-olkiluoto-3-completed, accessed 4 June 2018.

964 - IAEA, "IAEA Mission Sees Safety Commitment at Finland's New Olkiluoto Reactor Before Planned Start in December", Press Release, 22 March 2018, see https://www.iaea.org/newscenter/pressreleases/iaea-mission-sees-safety-commitment-at-finlands-new-olkiluoto-reactor-before-planned-start-in-december, accessed 4 June 2018.

nued deterioration in market prices and increased risk of higher production costs related to TVO's third nuclear power plant, Olkiluoto-3".[965] In May 2016, S&P lowered its rating for the company to "junk" (speculative grade 'BB+/B', stable outlook). This was said to be both as a result of the deterioration in the Finish power prices and most damningly:

> Future prices are currently predicted by the market to be below TVO's expected costs of production, when the third nuclear power plant Olkiluoto 3 (OL3) is commissioned in 2018/2019... We assess TVO's financial risk as significant based on its high debt leverage, which has increased due to cost overruns in the OL3 project.[966]

The stable outlook is based, amongst others, on the assumption that there will be "no further cost overruns in the completion of OL3".[967]

In October 2017, S&P placed its long-term corporate credit rating 'BB+' on TVO on CreditWatch with negative implications. The decision reflects the risk that TVO's financial flexibility

> ...could diminish as a result of additional delays or weaker counter parties in the Olkiluoto-3 EPR project (faces higher risk of a liquidity squeeze; one of TVO's key shareholders credit quality is under pressure) that could further increase TVO's high financial leverage.[968]

Following the settlement agreement TVO reported on 22 March 2018, that S&P's affirmed its long-term corporate credit rating 'BB+' for TVO but removed it from CreditWatch Negative.[969] According to S&P, the stable outlook is due to the settlement agreement, which will provide the plant supplier with the capacity and incentives to complete the project with no material delay or cost overrun for TVO.

The problems produced by the OL3 project did not prevent TVO from filing an application, in April 2008, for a decision-in-principle to develop "OL4", a 1.0-1.8 GW reactor to start construction in 2012 and enter operation "in the late 2010s".[970] However, by May 2015, TVO had decided not to apply for a construction license.[971]

In parallel, Fortum Power has been planning a similar project. In January 2009, the company Fennovoima Oy applied to the Ministry of Employment and the Economy for a decision-in-principle on a new plant at one of three locations—Ruotsinpyhtää, Simo, or Pyhäjoki. This was narrowed down to the latter site. Startup was planned for 2020. In March 2014, Rosatom, through a subsidiary company ROAS Voima Oy, completed the purchase of 34 percent of Fennovoima for a price, which was not disclosed,[972] and then in April 2014 a "binding decision to construct" an AES-2006 reactor was announced. In December 2014, the Finnish Parliament voted in favor

965 - S&P, "Finnish Nuclear Power Producer TVO Downgraded To 'BBB-/A3'; Outlook Negative", 28 May 2015.

966 - S&P, "Finland-Based Nuclear Power Producer TVO Downgraded To 'BB+' From 'BBB-' On Reduced Cost Competitiveness; Outlook Stable", 23 May 2016.

967 - Ibid.

968 - *4-traders*, "Fortum Oyj : Standard and Poor's placed TVO's credit rating 'BB+' on CreditWatch Negative", 19 October 2017, see http://www.4-traders.com/FORTUM-OYJ-1412461/news/Fortum-Oyj-Standard-and-Poor-s-placed-TVO-s-credit-rating-BB-on-CreditWatch-Negative-25316545/, accessed 4 June 2018.

969 - TVO, "Standard & Poor's removed TVO's credit rating from CreditWatch Negative", 22 March 2018, see https://www.tvo.fi/news/1969, accessed 4 June 2018.

970 - TVO, "Construction of a Nuclear Power Plant Unit at Olkiluoto—General Description—OL4", August 2008.

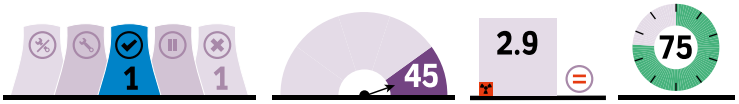
971 - TVO, "TVO's Board of Directors proposes that OL4 construction license will not be applied now", Press Release, 13 May 2015, see http://www.tvo.fi/news/1596, accessed 9 July 2018.

972 - Fennovoima, "Rosatom acquired 34% of Fennovoima", Press Release, 27 March 2014.

of a supplement to the decision-in-principle to include Rosatom's reactor design.[973] A construction license-application was submitted at the end of June 2015. In September 2015, the Finnish Safety Authority STUK began assessing the Hanhikivi-1 called project, which would take until the end of 2017.[974] As of 1 July 2018, STUK had not issued a construction license. However, site-preparation work and rock blasting reportedly already began in January 2016.[975] Actual construction is scheduled to start some time in 2018, with completion expected in 2024.[976] However, as WNISR2017 reported, the schedule appears overly optimistic—just like in many other Rosatom projects—as the "first batch of documentation" for the construction license application has only been transmitted to the Finnish safety authorities on 1 November 2016.[977]

Subsequently, in November 2017, Fennovoima Oy was instructed by STUK that it "must improve their operations before they are in a position to start the construction work."[978] STUK warned that "among other things, Fennovoima must improve the supervision of the organizations involved in the planning and construction of the nuclear power plant. The safety culture of RAOS Project, which is the plant supplier, and the main contractor Titan 2 currently does not fulfill the Finnish expectations".[979]

The Netherlands



The Netherlands operates a single, 45-year-old 480 MW PWR that provided 3.26 TWh in 2017 and 2.9 percent of the country's electricity, compared with 3.75 TWh or 3.4 percent of the country's power in 2016 (maximum of 6.2 percent in 1986).[980] In late 2006, operator and Government reached an agreement to allow operation of the reactor to continue until 2033.[981]

In January 2012, the utility DELTA announced it was putting off the decision on nuclear new-build "for a few years" and that there would be "no second nuclear plant at Borssele for the time being".[982] No utility is currently showing any interest in pursuing new-build. On the contrary, the nuclear utilities are struggling with shrinking income and increasing costs. German utility RWE AG that holds 30 percent of Borssele operator EPZ (Elektriciteits Produktiemaatschappij Zuid-Nederland), reported for 2017 a €58 million (US$62 million) im-

973 - *WNN*, "Parliament approves Fennovoima's amendment", 5 December 2014, see http://www.world-nuclear-news.org/NN-parliament-approves-Fennovoimas-amendment-5121401.html, accessed 8 July 2018.

974 - STUK, "STUK will start the Construction License safety review and assessment of Fennovoima's project", Press Release, 8 September 2015, see https://www.stuk.fi/web/en/-/stuk-will-start-the-construction-license-safety-review-and-assessment-of-fennovoima-s-project, accessed 9 July 2018.

975 - *PIE*, "PIE's New Power Plant Project Tracker", February 2016.

976 - *WNN*, "Daily", 21 March and 8 June 2017.

977 - *WNN*, "Daily", 2 November 2016.

978 - STUK, "STUK demands a better safety culture from the Fennovoima nuclear power plant project", 9 November 2017, see http://www.stuk.fi/web/en/-/stuk-demands-a-better-safety-culture-from-the-fennovoima-nuclear-power-plant-project, accessed 4 June 2018.

979 - Ibidem.

980 - BP, "Statistical Review of World Energy", June 2014.

981 - *WNA*, "Nuclear Power in the Netherlands", Updated February 2017, see http://www.world-nuclear.org/info/inf107.html, accessed 9 July 2018.

982 - DELTA, "DELTA puts off decision for a few years, no second nuclear plant at Borssele for the time being", Press Release, 23 January 2012.

pairment loss for EPZ, as in 2016.[983] Dutch utility Delta that holds the majority 70 percent of EPZ is losing money to a point that it fears bankruptcy. In 2016, Delta asked the Dutch government for support, but Economic Affairs Minister Henk Kamp ruled out to put money into Borssele, while he was prepared to offer financial guarantees for the company's "healthy parts" (network company Enduris and water company Evides), if they were put into a new company.[984] An assessment in 2017 by financial management consultancy Spring Associates demonstrated that electricity prices would have to double to make the nuclear plant profitable again, an unlikely scenario. The most economic scenario identified would be immediate shutdown of the reactor and delayed decommissioning, according to the analysts.[985]

In June 2014, EPZ started using uranium-plutonium Mixed Oxide (MOX) fuel at Borssele. EPZ is currently the only remaining foreign customer for commercial spent fuel of Orano's La Hague reprocessing plant. The plan to consume all of the plutonium that is separated in as much as 40 percent MOX in the core.[986] Short-term closure would jeopardize the plan.

As in other countries, the Dutch energy sector is undergoing profound restructuring. EPZ owner Delta has been renamed PZEM (Provinciale Zeeuwse Energie Maatschappij N.V.) in early 2017, parts (not Borssele) of which then has been sold to Stedin Holding, as part of the unbundling of production and networking activities.[987]

In 2017, PZEM reported a loss of €200 million (US$240 million) for Borssele and has reported that it expects to make an overall company loss of €70 million (US$82 million) in 2018.[988] The company is required to establish a €600 million decommissioning fund by the time the reactor is closed in 2033, which would be even more problematic, if the reactor did close early.

In May 2018, it was reported that PZEM had not fulfilled its obligations to invest €100 million (US$126 million) in renewable energy and energy conservation measures, which was a requirement condition set by the government in 2006 for continued operation of Borssele.[989] However, the government did not take action, in part due to the investment of RWE (30 percent ownership of Borssele), which did meet its financial commitments. The call by the Zeeland provincial council for national support for Borssele while debated in the national parliament has yet to yield any government intervention.[990]

983 - RWE, "Annual Report 2017", 2017, see http://www.rwe.com/web/cms/mediablob/en/3876342/data/3759768/6/rwe/investor-relations/reports/2017/RWE-annual-report-2017.pdf, accessed 7 June 2018.

984 - *DutchNews*, "Government won't give financial support to Borssele nuclear plant", 21 October 2016, see http://www.dutchnews.nl/news/archives/2016/10/96743-2/, accessed 9 July 2018.

985 - *DutchNews*, "Government investment in nuclear power plant financially risky: report", 4 October 2016, see http://www.dutchnews.nl/news/archives/2016/10/government-investment-in-nuclear-power-plant-financially-risky-report/, accessed 9 July 2018.

986 - Jan Wieman, "Borssele moves to MOX", Fuel Cycle Manager, EPZ, published in *NEI*, 11 March 2015, see http://www.neimagazine.com/features/featureborssele-moves-to-mox-4530062/, accessed 9 July 2018.

987 - Stedin Group, PZEM, "Delta Network Continues as Part of the Stedin Group", Press Release, 31 March 2017, see https://www.pzem.nl/sites/default/files/PRESS RELEASE STEDIN GROEP PZEM.pdf, accessed 9 July 2018.

988 - *Het Financieele Dagblad*, "PZEM expects € 70 million loss next year" 17 December 2017, (in Dutch), see https://fd.nl/ondernemen/1232193/pzem-verwacht-volgend-jaar-70-mln-verlies, accessed 7 June 2018.

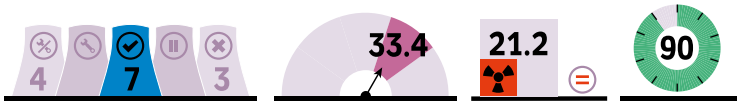
989 - *Het Financieele Dagblad*, "Energy company PZEM renounces at Borssele nuclear power plant, but receives respite from Minister Wiebes", 21 May 2018, see https://fd.nl/ondernemen/1254824/energiebedrijf-pzem-verzaakt-bij-kerncentrale-borssele-maar-krijgt-respijt-van-minister-wiebes, accessed 7 June 2018.

990 - *Het Financieele Dagblad*, "PZEM also in the red figures in 2017", 6 June 2018, see https://fd.nl/ondernemen/1257113/pzem-lijdt-verlies-van-70-mln-in-2017, accessed 7 June 2018.

In May 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.[991] The convention is an international environmental agreement under the auspices of the UN Economic Commission for Europe which addresses access to information and public participation. The preliminary ruling by Aarhus requires the Dutch government conduct an Environmental Impact Assessment (EIA), which would involve stakeholders in the Netherlands, but also 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 fact, Borssele has become synonym for some of the lowest offshore wind energy costs in Europe during 2016, coming in at approximately US$60/MWh for the Borssele 3&4 projects (about 700 MW). This new level not only reduced the cost of offshore wind energy by about half, "it also put the technology on the point of the price curve that was not forecasted to be reached before 2020-21", according to the Renewables 2017–Global Status Report.[992]

Spain



Spain operates six reactors, following the decision to permanently shut down the 47-year old Garoña reactor in August 2017, when the then government refused to approve license renewal. Garoña has not produced electricity since 2012 and is considered in permanent shutdown since WNISR2013. Nuclear plants provided 55.6 TWh in 2017 or 21.2 percent of the country's electricity in 2017, almost identical to 2016 with 56.1 TWh or 21.4 percent (maximum of 38.4 percent in 1989). Beyond the de-facto moratorium that has been in place for decades, then Premier Jose Luis Zapatero announced in April 2004 that his government would "gradually abandon" nuclear energy, while increasing funding for renewable energy. The first unit (José Cabrera) was shut down at the end of 2006. Zapatero confirmed the nuclear phase-out goal following his reelection in 2008, and then Industry Minister Miguel Sebastian stated that "there will be no new nuclear plants".[993]

The Ministry of Energy, Tourism and Digital, on 1 August 2017, announced its refusal to approve the renewal operating license for Garoña.[994] The decision was justified on the basis of submissions presented by institutions, associations and companies involved in the process and has also considered the need to have the planning that the Government plans to adopt in the field of energy and climate. In terms of the implications for other reactor operations in Spain, the Ministry explained that Garoña was considered an exception, "since it is the only plant that has not been operational for more than four years and during this time, it has been verified that the lack of electricity production of this plant has not had a significant impact on the

991 - UNECE, "ACCC/C/2014/104 Netherlands", UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, 25 May 2018, see https://www.unece.org/environmental-policy/conventions/public-participation/aarhus-convention/tfwg/envppcc/envppcccom/acccc2014104-netherlands.html, accessed 7 June 2018.

992 - REN21, "Renewables 2017—Global Status Report", June 2017.

993 - *Reuters*, "Spain Insists on Energy Saving, Not Nuclear Plants", 21 January 2009, see https://in.reuters.com/article/spain-nuclear/spain-insists-on-energy-saving-not-nuclear-plants-idINLL64460720090121, accessed 8 July 2018.

994 - Ministry of Energy, "Energy denies the renewal of Garoña's operating authorization", 1 August 2017, see http://www.minetad.gob.es/es-ES/GabinetePrensa/NotasPrensa/2017/Paginas/denegacion-garona20170801.aspx, accessed 8 July 2018.

electrical system."[995] At the same time Ignacio Galan, chairman of Iberdrola, has said Garoña is not economically viable,[996] with investment to bring it back on line and its operation described as potentially ruinous to the utility.[997]

In January 2018, it was disclosed that the Almaraz-1 and -2, and Vandellos-2 reactors are on track to apply for operational license renewal to operate beyond 40 years. An official from Centrales Nucleares Almaraz Trillo and Asociacion Nuclear Asco Vandellos, told trade journal *Nucleonics Week* (*NW*) that all technical documents to date have been submitted to CSN with plans to formally apply in spring 2018. As of 1 July 2018, there is no confirmation that applications have been submitted.[998] The twin units at Asco's operational licenses expire in 2021 with applications for renewal scheduled to be submitted in September 2018.[999] The Cofrentes reactor license runs to 2021.[1000]

The end of the conservative government of Mariano Rajoy and the forming of the new government in May 2018 under Socialist Party (PSOE) leader Pedro Sánchez is likely to see a dramatic shift in overall energy and climate policy over the coming year. The PSOE had a policy platform in 2016 that focused on energy efficiency and renewable energy, while reducing fossil fuel use. The party also committed to review the decision on the installation of Centralized Temporary Storage for spent fuel (ATC) of Villar de Cañas and will implement a timetable for the closure of nuclear power plants with 40 years of life.[1001]

> *"Spain will return to the group of countries that work the most towards clean energy"*

Prior to entering government the PSOE issued a report in March 2018 that proposed the closure of coal-fired plants and nuclear plants by 2025.[1002] With a decision to merge the Energy and Environment Ministries, the new Minister for Ecological Transition, Teresa Ribera,[1003] has said that there will be a major revision in renewable energy policy, as "Spain will return to the group of countries that work the most towards clean energy."[1004]

995 - Ministry of Energy, 2017.

996 - Jon Stibbs, "Spanish nuclear sector under threat as one Garona owner wants out", ICIS, 20 April 2017, see https://www.icis.com/resources/news/2017/04/20/10098983/spanish-nuclear-sector-under-threat-as-one-garona-owner-wants-out/, accessed 8 July 2018.

997 - Fernando Barciela, "Electricity Companies, Divided Over The Future Of Nuclear Energy In Spain", *The Corner*, 4 May 2017, see http://thecorner.eu/spain-economy/electricity-companies-nuclear-energy-spain/63987/, accessed 8 July 2018.

998 - *NW*, "First Spanish nuclear plants on track for license renewal", 2 February 2018.

999 - Ibid.

1000 - CSN, "Central Nuclear De Cofrente", see https://www.csn.es/documents/10182/989190/Central%20Nuclear%20de%20Cofrentes, accessed 8 July 2018.

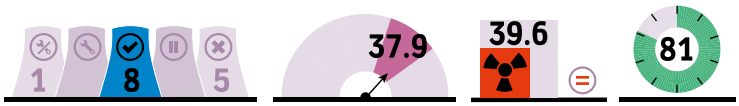
1001 - PSOE, "Programa Electoral Elecciones Generales 2016", 2016, see http://www.psoe.es/media-content/2016/05/PSOE-Programa-Electoral-2016.pdf (in Spanish), accessed 5 June 2018.

1002 - Ibid.

1003 - *Publico*, "Teresa Ribera, a 180 degree turn in the fight against climate change", 6 June 2018, (in Spanish), see http://www.publico.es/politica/teresa-ribera-teresa-ribera-giro-lucha-cambio-climatico.html, accessed 8 July 2018.

1004 - *El Pais*, "Spain's new PM signals change of tack on climate change", 6 June 2018, (in Spanish), see https://elpais.com/elpais/2018/06/06/inenglish/1528270804_597351.html, accessed 8 July 2018.

Sweden



Sweden's nuclear fleet of nine reactors generated 63.1 TWh, 40 percent of the country's electricity production in 2017, compared with 60.65 TWh and an identical share in power generation in 2016. The Ringhals-2 reactor, which had entered the LTO category in WNISR2016, was brought back on-line in November 2016, after over two years of shutdown for repairs. The reactor restarted in spite of a "corroded reactor containment liner" after the Swedish Radiation Safety Authority (SSM) had granted an "exemption from its official regulations" for its remaining lifetime.[1005] Ringhals-2 is scheduled for shutdown in 2019, followed by Ringhals-1 in 2020.

On the other hand, Sweden's oldest nuclear reactor, Oskarshamn-1, was closed permanently on 17 June 2017 after close to 46 years of service.[1006] Thus the total number of operating reactors stands at eight as of mid-2018.

State-utility Vattenfall co-owns seven reactors,[1007] OKG (Oskarshamns Kraftgrupp AB)[1008] owns the eighth, Oskarshamn-3. The respective majority owner operates the plant. Vattenfall also holds shares in three German nuclear power plants, two that were closed after 3/11 (Brunsbüttel, Krümmel) and one scheduled for shutdown in 2021 (Brokdorf).

Sweden is a large power exporter, with Finland being the largest importer. In 2017, net exports stood at 16.3 TWh, equivalent to over a quarter of the nuclear generation.[1009] Exports had reached a historic maximum of 22.6 TWh in 2015.[1010]

Sweden decided in a 1980 referendum to phase out 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 shut down in 1999 and the second one (Barsebäck-2) in 2005.

> *"Government support for nuclear energy, in the form of direct or indirect subsidies, cannot be counted upon"*

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 shut down. The latest "traditional Swedish compromise" in June 2016, an agreement was reached on future energy policy.[1011] The Red-Green Government and three opposition parties confirmed the baseline of the 2010 agreement and fixed a 2040 target for a 100-percent renewable electricity mix. Reactor operators are planning to apply for life extension for six reactors,

1005 - *WNN*, "Daily", 4 November 2016.

1006 - WNISR, "Sweden Retires First Commercial Nuclear Reactor (Oskarshamn-1)", 20 June 2017, see https://www.worldnuclearreport.org/Sweden-Retires-First-Commercial-Nuclear-Reactor-Oskarshamn-1.html, accessed 9 July 2018.

1007 - Ringhals-1–4 (Vattenfall 70.4%, E.ON 29.6%), Forsmark-1–3 (FKG, Vattenfall 66%, Mellansvensk Kraftgrupp 25.5%, E.ON 8.5%)

1008 - OKG is owned by Uniper Sverige (formerly Sydkraft), an E.ON spinoff, for 54.5% and Fortum for 45.5%.

1009 - ENTSOE, "Physical Energy and Power Flows", European Network of Transmission System Operators, Undated, see https://www.entsoe.eu/data/power-stats/physical-flows/, accessed 9 July 2018.

1010 - Svenska kraftnät, "Sveriges Import/Export Samt Transitering", 2017.

1011 - 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, see https://www.government.se/49d8c1/contentassets/8239ed8e9517442580aac9bcb00197cc/ek-ok-eng.pdf, accessed 7 June 2018.

which see operation into the early 2040's. The 2016 policy agreement also allows for the building of new reactors, but, as in the previous agreement, only in replacement and not in addition to existing ones. In addition, the agreement stipulates: "Government support for nuclear energy, in the form of direct or indirect subsidies, cannot be counted upon".[1012]

In April 2015, Vattenfall decided "to change direction for operational lifetimes of Ringhals-1 and 2",[1013]. The reasons given were continued low electricity prices and increasing production costs. As for Vattenfall's five other reactors, the previously planned "at least 60 years of operational lifetime, until the beginning of 2040s," remains.[1014] Following the energy agreement, Vattenfall's Board of Directors decided to invest in independent core-cooling systems for the three Forsmark reactors, a prerequisite for continued operations beyond 2020.[1015]

Swedish operators have pushed uprating projects to over 30 percent. OKG, the second Swedish operator, implemented a 33 percent uprate at Oskarshamn-3 with a two-year delay. At Oskarshamn-2, shut down since June 2013, major uprating works were under way, but has been "indefinitely postponed" in June 2015. Vattenfall had cancelled its planned uprate for Forsmark-3 in November 2014, profitability calculation had deteriorated over the year.

Currently, six of Sweden's reactors were scheduled for sixty-year operation into the 2040's, with closure of the last reactor in 2045.[1016] However, by that time Sweden now plans to have 100 percent of its electricity generated by renewable energy.

While Vattenfall is still struggling with low prices on the European power markets, it continued to increase its customer base and improved operating results in 2017. Vattenfall has now a modest total of 2.8 GW of renewables in operation in various countries but has another 7 GW under development. The company plans €5 billion investment in renewables in the coming years.[1017]

On 1 July 2017, the Swedish government started phasing out its capacity tax on nuclear power production. Utilities had warned the government that without the repeal of the tax they may shut more reactors permanently.[1018] "The tax reduction will be 3 billion crowns per year (US$343 million)... This tax relief is (for us) more pointed towards investments on the prolongation of Swedish nuclear," Vattenfall stated.[1019] The decision prompted Vattenfall on 17 November 2017 to announce that it would invest SEK900 million (US$105.8 million) in

1012 - Ibidem.

1013 - Vattenfall, "Vattenfall changes direction for operational lifetimes of Ringhals 1 and 2", Press Release, 28 April 2015, see https://corporate.vattenfall.com/press-and-media/press-releases/2015/vattenfall-changes-direction-for-operational-lifetimes-of-ringhals-1-and-2/, accessed 9 July 2018.

1014 - Vattenfall, "Vattenfall will invest in Forsmark", 15 June 2016, see https://corporate.vattenfall.com/press-and-media/press-releases/2016/vattenfall-will-invest-in-forsmark/, accessed 9 July 2018.

1015 - Ibidem.

1016 - IAEA, "Asset Management At Nuclear Power Plants - With International Standards And Principles", Vattenfall, IAEA-CN-246-14, October 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-10-23-10-27-NPTDS/054_Frojd_Presentation.pdf, accessed 6 June 2018.

1017 - Vattenfall, "Increase renewables", 19 April 2018, see https://corporate.vattenfall.com/sustainability/production/increase-renewables/, accessed 7 June 2018.

1018 - *Reuters*, "Vattenfall puts pressure on Swedish government to cut nuclear tax", 28 April 2016, see https://www.reuters.com/article/vattenfall-nuclear-idUSL5N17V5HN, accessed 6 June 2018.

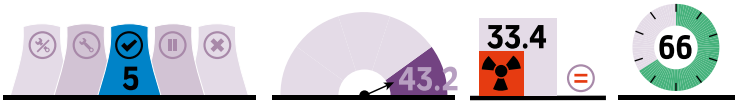
1019 - *Reuters*, "Sweden's nuclear tax phase-out to save Vattenfall SEK 3 bln/yr -CEO", 7 July 2017, see https://www.reuters.com/article/sweden-nuclear-vattenfall-idAFL8N1JY30H, accessed 6 June 2018.

the installation of independent core cooling systems at Ringhals-3 and -4.[1020] Following the Fukushima Daiichi nuclear accident the Swedish Radiation Safety Authority required the installation of such systems by 2020, a condition of granting approval for them to continue operation.[1021,1022] A critique of the so called stress tests performed on European nuclear reactors following the Fukushima accident, concluded: "In their current state, the four Ringhals reactors are not able to withstand a design basis earthquake (DBE)."[1023] In November 2017, Vattenfall announced that it had extended the current operational cycle of the Ringhals-1 and -2 for up six months to December 2020 and 2019 respectively, at which point the two reactors will be permanently shut down.[1024] Vattenfall had decided in June 2016 to install independent core cooling systems at its three Forsmark reactors.[1025]

Note:

WNISR has decided to add the Marviken reactor to its reactor database as "abandoned construction project". Marviken was a 100 MWe boiling water reactor moderated by heavy water and was located at Vikbolandet, east of Norrköping in Östergötland. Its construction was completed and cold-tested. It was designed for natural uranium fuel but never loaded. It was built as possible plutonium production reactor for the Swedish weapons program, but the construction turned out to have safety problems. The project was cancelled in 1970. Sweden gave up its nuclear weapons program and its signature of the Non-Proliferation Treaty (NPT) from 1968 also made the reactor obsolete.

Switzerland



Switzerland is the only non-EU Western European country generating nuclear power. Nuclear output was 19.5 TWh in 2017, the first time below 20 TWh since the nuclear buildup and the lowest level since 1984, the year the Leibstadt reactor—the most recent Swiss unit—started up. The Swiss load factor dropped to 66.1 percent, the fourth lowest in the world. Nuclear represented 31.7 percent of the country's electricity, down from a maximum of 43 percent in 1996.[1026] With an average age of 43.2 years (see Figure 49), Switzerland operates the oldest nuclear fleet and—with Beznau-1, age 49—the oldest reactor in the world (by length of commercial opera-

1020 - *NW*, "Vattenfall to install extra core cooling at Ringhals units", 23 November 2017.

1021 - IAEA, "Post-Fukushima Safety Upgrade Of Ringhals Unit 3 And 4, Technical Meeting on Operational Experience with Implementation of Post-Fukushima Actions in Nuclear Power Plants", 27-29 March 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-03-27-03-29-NPES/16_Lindback.pdf, accessed 6 June 2018.

1022 - Vattenfall, "Vattenfall invests in Ringhals upgrade", Press Release, 17 November 2017, see https://corporate.vattenfall.com/press-and-media/press-releases/2017/vattenfall-invests-in-ringhals-upgrade/, accessed 6 June 2018.

1023 - Antonia Wenisch, Oda Becker, "Critical Review of the EU Stress Test performed on Nuclear Power Plants", Greenpeace, May 2012, see https://www.greenpeace.de/sites/www.greenpeace.de/files/20120613-Critical-Review-of-EU-Stress-Test-Greenpeace.pdf, accessed 6 June 2018.

1024 - Vattenfall, "Vattenfall invests in Ringhals upgrade", Press Release, 17 November 2017, see https://corporate.vattenfall.com/press-and-media/press-releases/2017/vattenfall-invests-in-ringhals-upgrade/, accessed 6 June 2018.

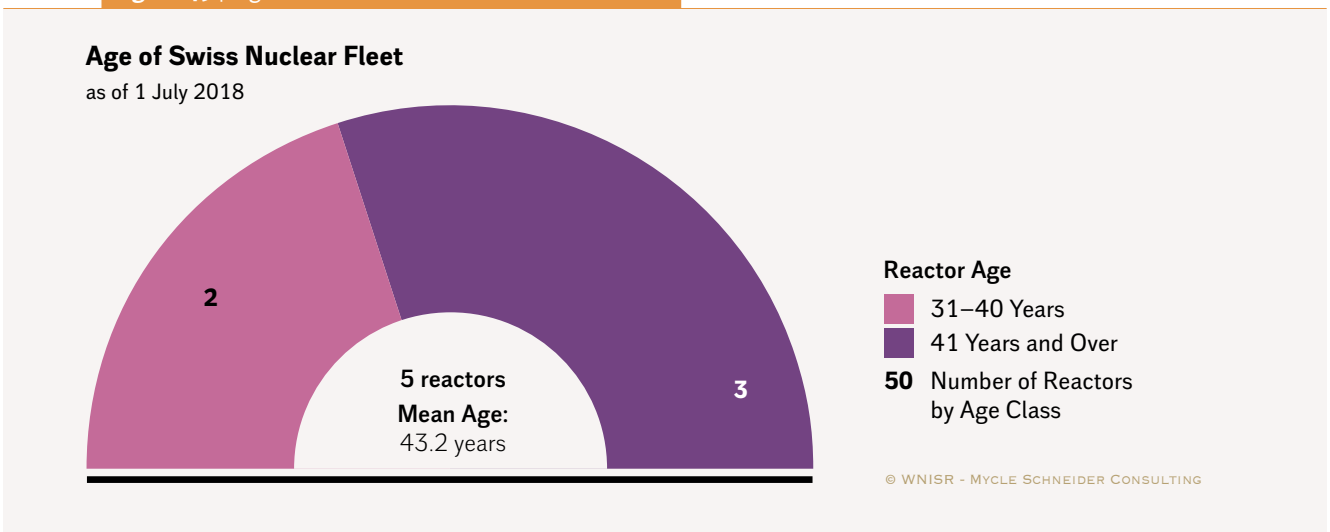
1025 - *NW*, "Vattenfall to install extra core cooling at Ringhals units", 23 November 2017.

1026 - SFOE, "Schweizerische Elektrizitätsstatistik 2017", Swiss Federal Office of Energy, June 2018, (in German), see http://www.bfe.admin.ch/themen/00526/00541/00542/00630/index.html?lang=en&dossier_id=00765, accessed 12 July 2018. The official national figures vary slightly from the IAEA-PRIS statistics that give 44.4 percent as the historic maximum.

tion). After almost three years of outage, Beznau-1 was restarted on 20 March 2018,[1027] and thus moved from the LTO category back into operation.

On 21 May 2017, 58 percent of the Swiss voters adopted 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 precise shutdown 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.[1028]

Figure 49 | Age Distribution of the Swiss Nuclear Fleet



Sources: WNISR2018 with IAEA-PRIS

The new legislation is indeed comprehensive, providing a framework for grid development regulation, renewable energy incentives, auto-consumption, energy efficiency and the 'organic phaseout' of nuclear power. The efficiency targets are ambitious, with reduction levels of per capita energy consumption—compared to the 2000 baseline—of 16 percent by 2020 and 43 percent by 2035, while electricity consumption is to decrease by 3 percent by 2020 and 13 percent by 2035. At that target date, domestic production of non-hydro renewable-energy based electricity is to reach 11.4 TWh, while already well-developed hydro should generate 37.4 TWh.[1029]

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."[1030] In January 2015, the federal regulator accepted the upgrades proposed by the operator in order to continue operating Mühleberg

1027 - Axpo, "Beznau nuclear power plant: Unit 1 back on grid" (Press Release), 20 March 2018, see http://www.axpo.com/axpo/ch/en/news/news/medienmitteilungen/2018/kernkraftwerk-beznau--block-1-wieder-am-netz-.html, accessed 30 April 2018.

1028 - SFOE, "Wichtigste Neuerungen im Energierecht ab 2018", 2 November 2017, (in German), see https://www.newsd.admin.ch/newsd/message/attachments/50166.pdf, accessed 12 July 2018.

1029 - Ibidem.

1030 - *NIW*, "Switzerland—News Briefs", 1 November 2013.

until 2019.[1031] In December 2015, BKW officially began the closure procedure. In March 2016, BKW communicated the date, when Mühleberg will be disconnected from the grid as of the 20 December 2019.[1032] On 20 June 2018, the Federal Energy Department has issued the formal shutdown decision and granted a general decommissioning license.[1033]

Following the reactor pressure vessel problems identified at the Belgian Doel-3/Tihange-2 reactors (see Belgium Section), inspections have been carried out at the two Beznau units, both 365 MW Westinghouse Pressurized Water Reactors (PWRs). At the pressure vessel of Beznau-1, a total of 925 crack indications, up to 7.5 x 7.5 mm in size and 60 mm in depth have been identified. According to operator Axpo, the defaults, with a high degree of confidence, would not be hydrogen flakes, as in the Belgian cases, but aluminum oxide enclosures from the fabrication process. At the pressure vessel of Beznau-2, 77 indications have been found with a maximum size of 20 x 50 mm.[1034] After evaluation of the identified defects in unit 2, in December 2015, the Swiss Federal Nuclear Safety Inspectorate ENSI, grants restart permission for the reactor, while unit 1 remained offline.

> *"the nuclear power plant in Beznau should be shut down at the earliest point in time"*

In November 2016, Beznau operator Axpo transmitted its safety case to the regulator with the expectation to restart unit 1 in spring 2017. But the safety authorities requested "additional information" and the reactor was then not expected to restart before 31 October 2017.[1035] In reality, Beznau-1 was reconnected to the grid only on 20 March 2018. The restart decision was given in spite of a damning report by two nuclear experts from Öko-Institut, Darmstadt, that found numerous "safety-relevant technical deficiencies", if compared with the German reactor safety standards.[1036] Franz Untersteller, Environment Minister of Baden-Wurttemberg, who commissioned the study, stated: "Considering the results of the expertise, the nuclear power plant in Beznau should be shut down at the earliest point in time."[1037] ENSI on 25 May 2018—two months after the Beznau restart and seven months after the Öko-Institut report publication—released a 35-page analysis of the report. ENSI stated that "most of the indicated safety-relevant technical deficiencies of the nuclear power plant Beznau either incorrect or of lesser importance".[1038]

1031 - ENSI, "Forderungen des ENSI für den Weiterbetrieb des Kernkraftwerks Mühleberg bis zur endgültigen Ausserbetriebnahme (EABN) im Jahr 2019", 23 January 2015.

1032 - BKW, "Kernkraftwerk Mühleberg geht am 20. Dezember 2019 definitiv vom Netz—Endgültige Einstellung des Leistungsbetriebs", Press Release, 2 March 2016, (in German), see http://www.bkw.ch/en/about-us/press-releases/detail/news/detail/News/kernkraftwerk-muehleberg-geht-am-20-dezember-2019-definitiv-vom-netz, accessed 15 June 2016.

1033 - UVEK, "Stilllegungsverfügung Kernkraftwerk Mühleberg vom 20 Juni 2018", Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation, SFOE, 20 June 2018, (in German), see https://bkw-portal-static.s3.amazonaws.com/Webcontent/bkw.ch/fileadmin/user_upload/Stilllegungsverf%C3%BCgung%20Kernkraftwerk%20M%C3%BChleberg%20vom%2020.%20Juni%202018.pdf, accessed 13 July 2018.

1034 - Christoph Pistner, "Beznau: Finding on the RPV", Presentation at INRAG, 27 February 2016.

1035 - Axpo, "Sicherheitsnachweis KKB 1: AXPO muss zusätzliche Informationen liefern", 16 June 2017.

1036 - Christoph Pistner, Simone Mohr, "Sicherheitsstatus des Kernkraftwerks Beznau", Öko-Institut, Darmstadt, August 2017.

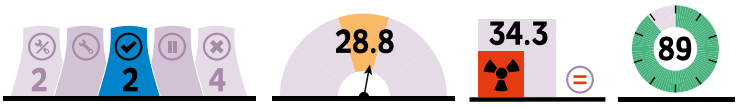
1037 - Umweltministerium Baden Württemberg, "Folgegutachten zum Sicherheitsstandard im Atomkraftwerk Beznau (Schweiz): Öko-Institut sieht trotz Verbesserungen nach wie vor gravierende Mängel", Press Release, 13 October 2017, see https://um.baden-wuerttemberg.de/de/service/presse/pressemitteilung/pid/folgegutachten-zum-sicherheitsstandard-im-atomkraftwerk-beznau-schweiz-1/, accessed 26 May 2018.

1038 - ENSI, "Stellungnahme zum Gutachten des Öko-instituts zum Sicherheitsstatus des Kernkraftwerks Beznau", Swiss Federal Nuclear Safety Inspectorate, 25 May 2018, see https://www.ensi.ch/de/dokumente/stellungnahme-zum-gutachten-des-oekoinstituts-zum-sicherheitsstatus-des-kernkraftwerks-beznau/, accessed 13 July 2018.

In 2016, Switzerland filed a negative electricity trade balance with net imports of 3.9 TWh, and, for the first time, the balance in monetary terms turned negative with a deficit of CHF145 million (US$150 million).[1039] In 2017, the trade deficit increased to 5.9 TWh and CHF217 million (US$217 million).[1040]

CENTRAL AND EASTERN EUROPE

Bulgaria



In Bulgaria, nuclear power provided 14.87 TWh or 34.3 percent of the country's electricity in 2017, practically unchanged from 2016 (15.01 TWh, 15 percent), but down from a maximum of 47.3 percent in 2002. At the country's only nuclear power plant, Kozloduy, there are now just two reactors operating, where originally there were six; the other four reactors were closed as part of the agreement for Bulgaria to join the EU. The load factors of the two remaining reactors was a percentage point lower than 2016, but significantly higher in 2017 (at 88.7 percent) than the average of their operating life (62.6 percent). The two VVER-1000 reactors are undergoing a relicensing program to extend their operating lifetimes for up to 60 years. In May 2016, it was reported that the technical work on the completion of the life-extension on unit 5 has been completed.[1041]

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 November 2015, the Bulgarian Prime Minister, Boyko Borisov, during a visit to China held talks on potential nuclear cooperation, which was followed by a Chinese delegation visiting Kozloduy in December 2015. It was suggested that Westinghouse, prior to its economic collapse, would team up with State Power Investment Corporation (SPIC) to construct further units at Kozloduy.[1042] Discussions were said to be also ongoing with CNNC, with a delegation meeting with the Prime Minister in Sofia in December 2016.[1043] The Bulgarian Government is reportedly also looking to Chinese sources, namely the Commercial Bank of China, to finance the completion of Belene,[1044] and in March 2018, CNNC were reported to have sent a letter, "declaring an interest" in the Belene project.[1045]

In August 2017, the Bulgarian Energy Minister, Temenuzhka Petkova, announced that in early 2018, the government planned to hold a tender for the sale of the partially constructed Belene project, which would be separated from the assets of the National Electric Company.

1039 - BFE, "Schweizerische Elektrizitätsstatistik 2016", June 2017.

1040 - Swiss Federal Office of Energy (SFOE), op.cit.

1041 - *Reuters*, "Russia's Rosatom completes upgrade of Bulgarian nuclear reactor", 31 May 2016, see https://uk.reuters.com/article/rosatom-bulgaria/russias-rosatom-completes-upgrade-of-bulgarian-nuclear-reactor-idUKL8N18S28W, accessed 26 April 2018.

1042 - C.F. Yu, "Will SPI Team Up with Westinghouse in Bulgaria?", *NIW*, 26 February 2016.

1043 - Georgi Gotev, "China eyes nuclear project in Bulgaria", *Euractiv*, 9 December 2016, see https://www.euractiv.com/section/energy/news/china-eyes-nuclear-project-in-bulgaria/, accessed 26 April 2018.

1044 - Gary Peach, "Can Bulgaria tempt the Chinese with Belene?", *NIW*, 16 December 2016.

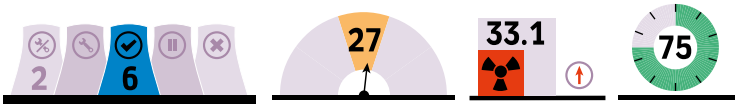
1045 - *NEI*, "Bulgaria's Belene NPP sparks Chinese interest", 27 March 2018, see http://www.neimagazine.com/news/newsbulgarias-belene-npp-sparks-chinese-interest-6096463/, accessed 26 April 2018.

The Government also said there would be no state guarantees or long-term power purchase agreements[1046]—conditions that will restrict and likely rule out any potential private investors. However, the Government is also seeking to support new-build by separating the assets and the liabilities of Belene, therefore attempting to increase the chances that the facility could be privatized.

The Bulgarian Academy of Science produced a report on request of the government to assess whether there are viable financial ways to continue the Belene project. An early version leaked in mid-2017 made clear that these did not exist. But in November 2017, the Academy came up with a report containing one potential avenue to complete Belene: it had to be cheaper than under the previous project with €10.15 billion ($12.4 billion), and the price of capital would be under 4.6 percent interest.[1047] As a result, the government proposed a revival of the project with Chinese support, but without any state involvement.[1048]

Consequently, there remains confusion over the possible future of Belene, with the Macedonian Ambassador for Bulgaria, calling for a joint project,[1049] and the Energy Minister saying that some of the Russian equipment in Belene will be sold and that Belene might still proceed.[1050] Although there remains domestic resistance to the project, with right wing party 'Democratic Bulgaria' opposing the project on economic grounds.[1051] However, in June 2018, the Parliament approved, by 182 to 14 with two abstentions, a proposal to lift the ban on construction at Belene. The motion will enable the government to start tendering for a strategic investor, but without state guarantees or preferential power prices.[1052] Under these conditions, given the experience in the rest of Europe, it will be difficult for the project to proceed.

Czech Republic



The Czech Republic has six Russian-designed reactors in operation at two sites, Dukovany and Temelín. The former houses four VVER440-213 reactors, the latter two VVER-1000-320 units. In 2017, nuclear plants generated 26.8 TWh or 33.1 percent of the electricity, up from 22.7 TWh or 29.4 percent in 2016. The Czech Republic has the lowest load factor of any country in Central and Eastern Europe and in 2017 the reactors averaged 74.9 percent availability. While

1046 - *NEI*, "Bulgaria plans privatisation and sale of Belene NPP project", 22 August 2017, see http://www.neimagazine.com/news/newsbulgaria-plans-privatisation-and-sale-of-belene-npp-project-5906032/, accessed 26 April 2018.

1047 - *NucNet*, "Reviving Bulgaria's Belene Project Could Be Economically Viable, Says Academy Report", 17 November 2017, see https://www.nucnet.org/all-the-news/2017/11/17/reviving-bulgaria-s-belene-project-could-be-economically-viable-says-academy-report, accessed 22 May 2018.

1048 - *Sofia News Agency*, "The Bulgarian Cabinet said 'Yes' to Restart the Nuclear Power Plant 'Belene', China Wants to Invest", *novinite.com*, 16 May 2018, see http://www.novinite.com/articles/190138/The+Bulgarian+Cabinet+said+%22Yes%22+to+Restart+the+Nuclear+Power+Plant+%22Belene%22%2C+China+Wants+to+Invest, accessed 22 May 2018.

1049 - Alex Dimchev, "Macedonian Ambassador Calls for the Construction of the Belene Power Plant in Bulgaria", *EU Scoop*, 27 February 2018, see https://www.euscoop.com/en/2018/2/27/macedonia-bulgaria-belene-powerplant, accessed 26 April 2018.

1050 - *TASS*, "Bulgaria may resume construction of Belene nuclear power plant with Russian equipment More", Russian News Agency, 2 March 2018, see http://tass.com/economy/992561, accessed 26 April 2018.

1051 - Alex Dimchev, "Democratic Bulgaria Speaks Out Against Belene NPP", *EU Scoop*, 19 April 2018, see https://www.euscoop.com/en/2018/4/19/democratic-bulgaria-against-npp-belene, accessed 26 April 2018.

1052 - Slav Okov, "Bulgaria Resumes East Europe's Biggest Atomic Project in Decades", *Bloomberg*, 7 June 2018, see https://www.bloomberg.com/news/articles/2018-06-07/bulgaria-resumes-east-europe-s-biggest-atomic-project-in-decades, accessed 5 July 2018.

this is somewhat below the lifetime average (77.6 percent) it is significantly above that of 2016, at 66.9 percent. The averages for the Temelín units are significantly higher than for Dukovany.

The country was a net exporter of 13 TWh of electricity in 2017, equivalent to around half of the nuclear output.

The Dukovany units were started up during 1985–87 and have already undergone a lifetime extension program under the expectation they would operate until 2025. In March 2016, the state regulator extended the operating license of Dukovany-1 indefinitely.[1053] With a similar request granted for unit 2 in July 2017 and for units 3 and 4 in January 2018.[1054] However, in February 2018, the head of the Czech State Office for Nuclear Safety, Dana Drábová, said that there was pressure from the EU to restrict the operation life of the reactors to 40 years.[1055] Furthermore, the fact that the life-time extension was decided without an environmental impact assessment is contested by Czech and Austrian NGOs under the Espoo and Aarhus Conventions.

In 2004, Government plans proposed the construction of at least two more reactors. After a series of unsuccessful attempts to tender out the project, in February 2014, the Government made it clear that it wouldn't offer a price guarantee for nuclear electricity and ČEZ abandoned its plans to issue tenders for new-build. Despite this, the Czech Industry and Finance Ministries continued to promote nuclear power. But there is little incentive or rationale for pushing for new construction in the short term. In principle, new capacity is foreseen for both locations, Dukovany and Temelín, to maintain employment after the closure of existing reactors. In the case of Dukovany, this would theoretically require commissioning new nuclear capacity by 2037. ČEZ is carrying out preparatory work and, in November 2017, an application for an Environmental Impact Assessment was filed.[1056]

In June 2016, the Government appointed former nuclear regulator Ján Štuller as Commissioner for Nuclear Energy to enable nuclear new-build. The Government has said that they are looking for a strategic partner for nuclear power in the Czech Republic, with interest in co-operation seen from Russia and South Korea.[1057] In addition, in March 2016, ČEZ signed an MoU with China General Nuclear Power Corporation (CGN) on the development of nuclear power and renewables, including on the assistance of ČEZ in the licensing in Europe of the Chinese Hualong design.[1058] In March 2017, it was reported that ČEZ had held talks with Westinghouse, Rusatom Overseas, EDF, AREVA-Mitsubishi, CGN and Korea Hydro and Nuclear Power, with the companies expressing an interest in building reactors in the Czech Republic.[1059]

1053 - *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 29 April 2018.

1054 - CEZ, "CEZ Group Annual Report 2017", 2018, see https://www.cez.cz/edee/content/file/investori/vz-2017/vz-2017-en.pdf, accessed 29 April 2018.

1055 - *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 29 April 2018.

1056 - CEZ, "CEZ Group Annual Report 2017", 2018.

1057 - *NIW*, "Czech Republic", 29 January 2016.

1058 - CGN, "CGN and CEZ Collaborate on Renewable and Nuclear Energy in the Czech Republic", 31 March 2016, see http://en.cgnpc.com.cn/encgn/c100101/2016-03/31/content_4f5e26ac4a92404ba5ef27c3b6a156d3.shtml, accessed 29 April 2018.

1059 - *WNN*, "ČEZ aims to restore full nuclear potential", 30 March 2017, see http://www.world-nuclear-news.org/C-CEZ-aims-to-restore-full-nuclear-potential-30031702.html, accessed 29 April 2018.

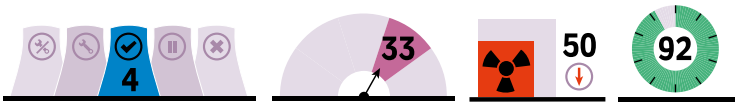
In March 2018, the Standing Committee on Nuclear Energy, made public its options on the future plans for financing nuclear new-build, these include:

- creating a new subsidiary of ČEZ to build the units with state backing;
- the purchase by the state of an existing part of ČEZ to build the plants; and
- splitting ČEZ to transfer its nuclear plants to a state-owned company.[1060]

The Committee will make its final recommendations to the Government later in 2018, with a Government decision expected soon after. 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.[1061] However, what is clear is that significant ČEZ restructuring and/or government finance is needed for nuclear new-build to be considered.

The consideration around restructuring of ČEZ are wider than nuclear power and the proposals are in line with similar developments of European utilities, such as RWE and Eon in Germany, where new companies have been formed to facilitate the further development of renewable energy and distribution activities, without being exposed to negative backlash from fossil fuel and nuclear activities.[1062] In the meantime, ČEZ has started in the end of 2017 an environmental impact assessment for a new unit at the Dukovany site,[1063] without clear indication which design is envisaged or when this project is to be realized. ČEZ also announced plans to prolong the lifetime of the Temelín power plant to 60 years.[1064]

Hungary



Hungary has only one nuclear power plant, at Paks, where four VVER 440-213 reactors provided a record 15.2 TWh or 50 percent of the country's electricity in 2017. The nuclear *share* is still down from 53.6 percent in 2014. The reactors started operation in the early 1980s and have been the subject of engineering works to enable their operation for up to 50 years (compared to their initial 30-year licenses), until the 2030s. The first unit received permission to operate for another 20 years in 2012, the second unit in 2014, the third in 2016 and the forth 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 Russian designs seemed to be the preferred option. 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 ($12.9 billion) investment. Previously the Russian offer was limited to

1060 - *WNN*, "Czech new build financing decision by mid-year", 27 March 2018, see http://www.world-nuclear-news.org/NN-Czech-new-build-financing-decision-by-mid-year-2703187.html, accessed 14 August 2018.

1061 - 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 22 May 2018.

1062 - Jan Lopatka, "UPDATE 1-Czech PM Babis to appoint experts to assess CEZ split", *Reuters*, 7 February 2018, see https://af.reuters.com/article/commoditiesNews/idAFL8N1PX5HS, accessed 15 April 2018.

1063 - CEZ, "ČEZ Asks for Environmental Impact Assessment of New Nuclear Units at Dukovany", 14 November 2017, see https://www.cez.cz/en/power-plants-and-environment/nuclear-power-plants/dukovany/construction-of-new-nuclear-power-sources/current-news/6.html, accessed 22 May 2018.

1064 - 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 22 May 2018.

80 percent of the financing.[1065] The Russian-Hungarian bilateral financing agreement consists of a €10 billion loan to the Hungarian state, which needs to be repaid from 2026, irrespective whether the project will be on line at that time.

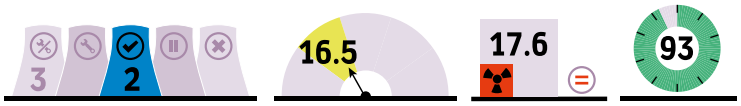
In November 2016, the European Commission cleared the award of the contract to Rosatom of any infringement on its procurement. The European Commission accepted the Hungarian justification for the decision that the "technical and safety requirements of the project can only be met by one company".[1066] This is surprising given the range of reactor designs, such as the European Pressurized Water Reactor (EPR), the AP1000 and ABWR that are under construction or under licensing review within the European Union.

In March 2017, the European Commission also approved the financial package for Paks II, acknowledging that it was State Aid, but satisfied that the impacts on the market would be kept to an acceptable level, if certain requirements were met, which included: any profits from the operation cannot be used to build or acquire additional generating capacity; Paks II, must be legally separated from Paks I; and that at least 30 percent of the power produced must be sold on the open market.[1067] However, in February 2018 the Austrian Government has challenged the validity of the decision, which will now be reviewed by the European Court of Justice.[1068] The legal challenge has subsequently been supported by the Luxembourg Government.[1069]

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.[1070]

In August 2017, Hungary's Foreign Minister said that construction work would begin at Paks II in January 2018 and that nothing could stop the construction.[1071] However, other reports suggest that a construction permit is now only expected in mid-2018.[1072] The project is said to be completed in 2024-25, but because of delays in the preparation phase, these dates are under some doubt.

Romania



Romania has one nuclear power plant at Cernavoda, where two Canadian-designed CANDU reactors are in operation. In 2017—almost identical to 2016—they provided 10.6 TWh or 17.6 percent of the country's electricity, compared to 20.6 percent in 2009. The Cernavoda

1065 - *NIW*, "Briefs - Hungary", 3 February 2017.

1066 - *NEI*, "EC agrees to Hungary's Paks II, but funding decision still awaited", 23 November 2016, see http://www.neimagazine.com/news/newsec-agrees-to-hungarys-paks-ii-but-funding-decision-still-awaited-5677338, accessed 23 November 2018.

1067 - European Commission, "State Aid: Commission clears investment in construction of Paks II nuclear power plant in Hungary", 6 March 2017, see http://europa.eu/rapid/press-release_IP-17-464_en.htm, accessed 29 April 2018.

1068 - *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 29 April 2018.

1069 - Eszter Zalan, "Luxembourg backs Austria against Hungarian nuclear plant", *EU Observer*, 5 March 2018, see https://euobserver.com/energy/141202, accessed 29 April 2018.

1070 - *NIW*, "Briefs—Hungary", 31 March 2017.

1071 - *AFP*, "2018 start for Russia-backed nuclear plant work", *Agence France Presse*, 28 August 2017, see http://www.nuclearpowerdaily.com/reports/2018_start_for_Russia-backed_nuclear_plant_work_Hungary_999.html, accessed 17 April 2018.

1072 - WNA, "Nuclear power in Hungary", February 2018, see http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/hungary.aspx, accessed 29 April 2018.

reactors are amongst the top lifetime performing reactors, with unit 2, the highest and unit 1 in third placed in the global league table of load factors. In 2017, their average load factor was 93.4 percent, the highest in the region.

Between 1982 and 1987, Romania started construction on five Canadian-designed reactors. Unit 1 was completed in 1996, and unit two 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 Euratom. As with other CANDU reactors, major refurbishment will be needed in the reactors, it is anticipated that this will occur in Unit 1 between 2026-28 and will cost €1.2-1.5 billion.[1073]

Various foreign companies have been involved in the attempts to revive the construction of units 3, 4 and 5. The penultimate involved Enel, CEZ, GDF SUEZ (Gaz de France), RWE, Iberdrola and ArcelorMittal, which established a company with the State nuclear corporation, called EnergoNuclear in 2008. However, one by one the foreign companies pulled out.[1074]

The latest attempt was launched by China General Nuclear Power Corporation (CGN), which signed a letter of intent in November 2013 with 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, the articles of incorporation of the new project company, the structuring of the project's financing and remarkably, CGN is to be the majority share owner of the project, with at least 51 percent of the shares.[1075] In January 2016, the Romania Government formally expressed support for the project and outlined the policies and measures that it would introduce to support it, this included energy market reform, changes to the electricity tariff, commitments on state guarantees and financial incentive policies. The cost of the completion of two reactors (720 MW each) is expected to be US$7.8 billion.[1076]

During 2016 and 2017, negotiations between CGN and Nuclearelectrica were said to be ongoing, although deadlines for construction and financing agreements have continually been extended. 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,[1077] a deadline which has been missed.

A key issue remains on the extent of financial support from the Romanian Government, and as with most other large power projects, especially nuclear, in Europe, the lower market price for electricity is likely to be a significant stumbling block. According to Nuclearelectrica, in late 2016, the break-even price for electricity from the project was about €82/MWh (US$94/

1073 - *Romania Insider*, "Romanian nuclear power plant reactor refurbishment to cost EUR 1.2-1.5 bln", 2 April 2018, see https://www.romania-insider.com/nuclear-power-plant-reactor-refurbishment-cost/, accessed 3 April 2018.

1074 - *WNA*, "Nuclear Power in Romania", October 2017, see http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/romania.aspx, accessed 29 April 2018.

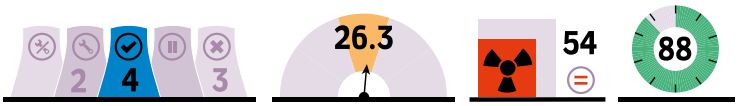
1075 - *WNN*, "Romania and China seal Cernavoda agreement", 19 November 2015, see http://www.world-nuclear-news.org/NN-Romania-and-China-seal-Cernavoda-agreement-10111501.html, accessed 29 April 2017.

1076 - *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 20 April 2017.

1077 - Phil Chaffee, "Romania: Can SNN end stalemate with CGN over Cernavoda ?", *NIW*, 22 September 2017.

MWh),[1078] which is well above the average price in 2017 of €32-41/MWh (US$39-50/MWh) in Romania.[1079]

Slovakia



In Slovakia, the state utility Slovenské Elektrárne (SE) operates two nuclear sites, Jaslovské Bohunice, which houses two VVER440 units, and Mochovce, which has two similar reactors. In 2017, their production remained stable at 14.0 TWh or 54 percent of the country's electricity—the third highest share in the world behind France and Ukraine. There is little difference in the load factors of the two sets of VVERs at Mochovce and Bohunice, despite the 15-year age difference between them, with an average of 88.3 percent in 2017.

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. Towards the end of 2014, ENEL announced that it was seeking to sell its share in SE and had received a number of nonbinding bids. In December 2015, it was announced that EPH (Energeticky a Prumyslovy Holding) was the winner of the bid, with a preliminary price of €750 million (US$812 million). Under the deal, ENEL will get €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 will be agreed one year after Mochovce is completed.[1080]

In February 2007, SE had announced that it was proceeding with the construction of Mochovce-3 and -4 and that ENEL had agreed to invest €1.8 billion (US$$_{2007}$2.6 billion). According to the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS), construction restarted in June 2009, and, at the time, the units were expected to generate power in 2012 and 2013 respectively.[1081] However, the project was beset with problems, and by May 2016, the estimate for the total costs of completion had risen to €5.1 billion (US$5.72016 billion), with completion at the end of 2016/early 2017.[1082] However, in March 2017, SE announced a considerable further delay in the project with operation expected only at the end of 2018 and 2019 for each unit. This is an additional two years of construction, while the officially expected cost increase is only €300 million (US$333 million),[1083] so further cost overruns are highly likely. According to SE, by March 2018, unit 3 was over 97 percent

1078 - *Nucnet*, "Negotiations On Construction Of Romania's Cernavoda-3 And -4 In 'Final Stage'", *Neutronbytes*, 29 October 2016, see https://neutronbytes.com/2016/10/29/romania-reports-progress-on-cernavoda-3-4/, accessed 29 April 2018.

1079 - PXE, "Price information from the Power Exchange Central Europe", see https://www.pxe.cz/?language=english, accessed 29 April 2018.

1080 - Tatiana Jancarikova, Jan Lopatka, "Enel sells stake in Slovak power group, including nuclear plant, to EPH", *Reuters*, 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 29 April 2018.

1081 - ENEL, "ENEL Starts Site Works at Mochovce 3–4 - Press release", 3 November 2008, see https://servizi.enel.it/eWCM/salastampa/comunicati_eng/1594888-1_PDF-1.pdf, accessed 29 April 2018.

1082 - *Spravy Pravda*, "Ďalšie peniaze na Mochovce? Žiga nemá oficiálnu informáciu", 5 May 2016, (in Slovak), see http://spravy.pravda.sk/ekonomika/clanok/392783-dalsie-peniaze-na-mochovce-ziga-nema-oficialnu-informaciu/, accessed 29 April 2018.

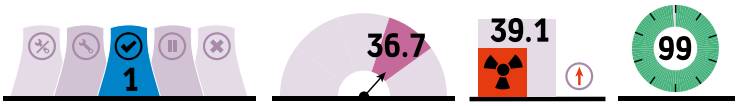
1083 - *WNN*, "Slovak utility increases Mochovce expansion budget", 31 March 2017, see http://www.world-nuclear-news.org/NN-Slovak-utility-increases-Mochovce-expansion-budget-31031701.html, accessed 29 April 2018.

complete and unit 4 about 85 percent.[1084] Completion of the projects is still expected at the end of 2018 and 2019 respectively.[1085] This new construction schedule means that the reactors are six years behind the 2009-schedule, when construction restarted, with an increase in budget from then €2.8 billion to €5.4 billion. However, in June 2018, the Slovak Prime Minister raised doubts, if even the revised schedule would be met, as he stated that "a number of problems arose during construction, and even now this makes us doubt whether this year's deadline for the third unit is realistic."[1086]

In addition to the delays and cost overruns, concerns have been raised about the state of the power market, with power prices currently at €30/MWh (US$33/MWh) and electricity demand following the sluggish economy. 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.

The Slovak state-owned utility JAVYS (Jadrova A VYradovacia Spolocnost) and the Czech utility CEZ in 2009 started a joint venture Jadrová energetická spoločnosť Slovenska, a.s. (JESS) to construct new nuclear capacity in Jaslovské Bohunice. JAVYS is currently responsible for the decommissioning at Jaslovské Bohunice of the A1 reactor and the two V1 reactors, as well as for Slovakia's radioactive waste management. The so-called Bohunice NJZ (Nová Jadrová Zdroj) 1200 MW new-build project is proposed to be completed before 2025 at a cost of €4-6 billion (US$4.5-6.8 billion). JAVYS owns 51 percent of the shares and CEZ 49 percent. CEZ sought in 2013 to sell this stake to Russian Rosatom, but negotiations failed in March 2014.[1087] Also later negotiations with China were fruitless. The Slovak Environment Ministry approved the environmental impact assessment report in April 2016, with construction scheduled to begin by 2021.[1088]

Slovenia



Slovenia jointly owns the Krsko nuclear power plant with Croatia—a 696-MW Westinghouse PWR. In 2017, it provided 6.0 TWh or 39.1 percent of Slovenia's electricity, an increase from 5.4 TWh or 35.2 percent in 2016, but below the maximum of 42.4 percent in 2005. The load factor of Krsko was the 22nd highest in the world in 2017, averaging 98.7 percent—that ranks Slovenia number one amongst all nuclear countries—which is significantly higher than its lifetime average of 80.5 percent.

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 plants operational life to 60 years, so that would continue until 2043, as well as to construct a dry storage facility for the spent fuel.[1089] In May 2016,

1084 - SE, "Mochovce s and 4 Project Completion", see https://www.seas.sk/mochovce-3-4-npp, accessed 29 April 2018.

1085 - *NIW*, "Slovakia", 16 February 2018.

1086 - *NIW*, "Slovakia: Are Mochovce's Headaches Over ?", 8 June 2018.

1087 - Chris Johnstone, "ČEZ left with problematic Slovak nuclear joint venture after Rosatom talks die", *Radio Praha*, 7 March 2014, see http://www.radio.cz/en/section/business/cez-left-with-problematic-slovak-nuclear-joint-venture-after-rosatom-talks-die, accessed 29 April 2018.

1088 - Energia, "Nová atómka v Bohuniciach má zelenú od MŽP", 19 April 2017, (in Slovak), see http://energia.sk/dolezite/jadrova-energia/nova-atomka-v-bohuniciach-ma-zelenu-od-mzp/19850/, accessed 29 April 2018.

1089 - *WNN*, "Partners agree on life extension for Krsko", 21 July 2015, see http://www.world-nuclear-news.org/C-Partners-agree-on-life-extension-for-Krsko-2107154.html, accessed 20 April 2017.

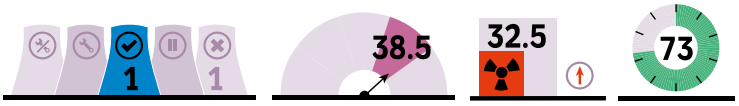
a spokeswoman for operator NEK (Nuklearna Elektrarna Krško) said: "The lifespan of Krsko has been extended providing that the plant passes a security check every 10 years with the next checks due in 2023 and 2033."[1090]

In March 2017 a contract, for an undisclosed amount, was given to the U.S. firm Holtec for the supply of a dry cask storage facility.[1091] Despite over 30 years of operation, disputes between the joint owners continue leading to a failure to agree new members of the management board.[1092]

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 made since.

FORMER SOVIET UNION

Armenia



Armenia has one remaining reactor at the Medzamor (also known as Metsamor) nuclear power plant, situated within 30 kilometers of the capital Yerevan. Armenian-2 provided 2.4 TWh or 32.5 percent of the country's electricity in 2017, a slight increase from 2016 with 2.2 TWh and 31.4 percent, but significantly below the maximum nuclear share of 45 percent in 2009. Armenia has the lowest lifetime load factor of any nuclear country in the world, averaging 53.4 percent. However, its 2017 average is significantly higher with 73.3 percent.

The reactor started generating electricity in January 1980 and is a first generation, Soviet designed reactor, a VVER 440-230. In December 1988, Armenia suffered a major earthquake that killed some 25,000 people and 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 against Armenia that led to significant power shortages, resulting in the government's decision in 1993 to re-open unit 2 at Medzamor. In October 2012, the Armenia Government announced that it would operate the Medzamor unit until 2026.

In June 2016, the European Nuclear Safety Regulators Group (ENSREG) issued the "EU Peer Review Report of the Armenian Stress Tests"[1093]. The report confirms numerous safety-related problems, and states, for example:

> Despite of various programmes of international aid and support, the progress in Severe Accident Management (SAM) programme development and implementation is quite slow and delayed with respect to the original schedules. Various essential issues are unsolved. (...) With respect to hardware modifications especially enhancements of the Emergency Core

1090 - *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 1 July 2018.

1091 - *NEI*, "Holtec to supply storage facility to Slovenia's Krsko", 3 March 2017, see http://www.neimagazine.com/news/newsholtec-to-supply-storage-facility-to-slovenias-krsko-5753449, accessed 20 April 2017.

1092 - Hina, "Krsko Nuclear Power Plant - Another Croatia-Slovenia Dispute", *Total Croatia News*, 25 April 2018, see https://www.total-croatia-news.com/business/27779-krsko-nuclear-power-plant-another-croatia-slovenia-dispute, accessed 29 April 2018.

1093 - ENSREG, "EU Peer Review Report of the Armenian Stress Tests", European Nuclear Safety Regulators Group, June 2016, see http://www.ensreg.eu/sites/default/files/attachments/2016-07-20_4259241_armenia_stress_tests_report-_ensreg_template_final.pdf, accessed 1 May 2018.

> Cooling System, containment tightness, hydrogen monitoring and control as well as containment spray system should be treated in priority.

The last sentence reads like a list of highest-level safety-related essentials.

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 Medzamor nuclear power plant and the early adoption of a road map or action plan to that effect."[1094]

Armenia-2's design lifetime—and with it its operating license—expired in September 2016. Since then, and at least until June 2018, when the operator was to submit an updated Safety Analysis Report (SAR), the reactor was operated on the basis of "temporary permissions". A final decision on a license for lifetime extension is not expected before 2021.[1095]

In December 2014, Armenia and Russia signed an intergovernmental agreement that would see the Russian Government finance a program of upgrading to let the reactor operate until 2026. [1096] The contract was signed in July 2015 for work to be funded by a Russian state loan of US$270 million and a grant of US$30 million.[1097] In December 2017, it was announced that Rosatom Service (JSC) had "completed equipment and systems supply" to Armenia.[1098] Both in 2018 and 2019 the nuclear reactor will be closed for periods of six months to allow for the implementation of the upgrading program.[1099]

The Armenia Government stated that "it is impossible to shut down the nuclear power plant without launching an alternative facility - in our case another nuclear reactor".[1100] However, this is not a universal view in the country as in October 2017, Justice Minister Davit Harutiunian said that maybe the country should consider alternatives to nuclear power: "Just imagine a possibility that it turns out tomorrow that modern technologies can generate the same amount of energy without a nuclear plant and that nuclear energy... is much more expensive for consumers. Which path should we opt for? Of course, modern technologies."[1101]

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. In March 2014,

1094 - 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 1 May 2018.

1095 - Leonti Chaloyan, "Armenia NPP Stress Tests Action Plan", IAEA, 27 March 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-03-27-03-29-NPES/15_Chaloyan.pdf, accessed 1 May 2018.

1096 - *Arka News Agency*, "Deputy minister says there is alternative to shutting down Armenian nuclear power plant", 10 April 2018, see http://arka.am/en/news/technology/deputy_minister_says_there_is_alternative_to_shutting_down_armenian_nuclear_power_plant/, accessed 11 April 2018.

1097 - *NEI*, "Armenian NPP prepares for life extension", 12 February 2016, see http://www.neimagazine.com/news/newsarmenian-npp-prepares-for-life-extension-4811203, accessed 1 May 2018.

1098 - Armenian NPP, "Armenian Nuclear Power Plant", 6 October 2017, see http://armeniannpp.am/en/info/news/hamatex-koordinacion-komitei-hertakan-nstashrjany.html, accessed 11 April 2018.

1099 - *Arka News Agency*, "Armenian nuclear power plant to be halted for six months in 2018 and 2019", 20 October 2017, see http://arka.am/en/news/technology/armenian_nuclear_power_plant_to_be_halted_for_six_months_in_2018_and_2019/, accessed 1 May 2018.

1100 - *Arka News Agency*, "Deputy Minister Says There Is Alternative to Shutting down Armenian Nuclear Power Plant", 11 April 2018.

1101 - Sargis Harutyunyan "Yerevan May Scrap Plans For New Nuclear Plant", *Azututyun.am*, 17 October 2017, see https://www.azatutyun.am/a/28799958.html, accessed 1 May 2018.

the energy minister admitted that it was having difficulty in attracting funds to start construction.[1102] In September 2016, Areg Galstyan stated: "We have approximately 10 years to start the construction of the new energy unit on the same place, where the Medzamor Nuclear Power Plant is located. We are 100 percent sure that the block will use pressurized water reactor. We have one, maximum two years to make the final decision on choosing the type of project."[1103] Although since then little progress appears to have been made with no clear choice on future technologies, with some proposing the construction of Small Modular Reactors (SMRs).[1104]

Russia

In Russia, 35 nuclear reactors provided a historic maximum of 190.2 TWh of electricity in 2017. Nuclear energy contributed 17.8 percent—up from 17.1 percent in 2016—to the country's electricity mix. Rosatom is hoping to further increase production in the coming years, with output in 2019 expected to reach 214 TWh.1105 Russia has shown a marked increase in its average load factor in recent years and in 2017 managed 80 percent, which compares to an average lifetime load factor of 65.1 percent.

The start of 2018 saw Russia make considerable progress in the development of new nuclear reactors, with the connection to the grid of the Rostov-4 reactor in February—35 years after its construction was first started[1106]—the first unit at the Leningrad-2 power station in March, bringing the fleet to 37 reactors, and the official launch of a two-reactor floating nuclear power plant. Once these are operational, Russia will only have three reactors under construction, Leningrad 2-2, Novovoronezh 2-2 and Kursk 2-1 whose construction started in April 2018.

The "floating reactors" (Akademik Lomonosov-1 and -2), are nominally 32 MWe each. These were ordered in February 2009 and were expected to be delivered to the customer at the end of 2012.[1107] In April 2018, the floating platform was put to sea, from its construction site in St Petersburg, to be towed to an interim birth in Murmansk, where fuel will be loaded, and the reactors tested. The boat arrived in May 2018. During the summer of 2019, it is expected to be taken to its final location of Pevek.[1108] Critics of the project point out that the risk of accidents on a floating nuclear plant is greatly increased because they are even more susceptible

1102 - *BNE Intellinews*, "Armenia denies plans to abandon nuclear power plant project", 28 March 2014, see http://www.intellinews.com/armenia-denies-plans-to-abandon-nuclear-power-plant-project-500000301/?archive=bne, accessed 1 May 2018.

1103 - *Arka News Agency*, "Armenia has two years to decide on type of new NPP unit", 28 September 2016, see http://arka.am/en/news/technology/armenia_has_two_years_to_decide_on_type_of_new_npp_unit/, accessed 1 May 2018.

1104 - *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 1 May 2018.

1105 - *NEI*, "Russia plant to boost nuclear power generation", 18 April 2017, see http://www.neimagazine.com/news/newsrussia-plans-to-boost-nuclear-power-generation-5789303/, accessed 25 April 2017.

1106 - See WNISR, "The construction Saga of Rostov Nuclear Reactors 3 and 4", 14 February 2018, see https://www.worldnuclearreport.org/The-Construction-Saga-of-Rostov-Reactors-3-and-4.html., accessed 14 August 2018.

1107 - *NEI*, "KLT-40S nuclear barge project still afloat", 9 March 2010.

1108 - Rosatom, "The world's only floating power unit 'Akademik Lomonosov' takes the sea" (Press Release), 28 April 2018, see http://rosatom.ru/en/press-centre/news/the-world-s-only-floating-power-unit-akademik-lomonosov-takes-the-sea/, accessed 30 April 2018.

to the elements, subject to threats of piracy, and if deployed widely would increase the risks of nuclear material proliferation.[1109]

Two VVER-1200 MW units were being built at the Leningrad nuclear power plant, at Sosnovy Bor, near St. Petersburg, where construction started in 2008 and 2010. At the time of ordering, the reactors were expected to start up in 2013 and 2016 respectively. Unit 1 was connected to the grid in March 2018.[1110]

Construction re-started on another VVER 320 reactor, at the Rostov nuclear power plant, with "new concrete" being poured in June 2010 (the 4th Unit at the power plant). First criticality was reached in December 2017 and commercial operation began in February 2018.[1111]

Construction started at the Baltic-1 unit, a 1109 MW VVER-491 reactor, in February 2012. However, construction was suspended in June 2013 for a variety of reasons, including recognition of the limited market for the electricity. Accordingly, WNISR pulled the project off the construction listing. Despite no indication that construction has restarted, the project remains "under construction" in IAEA statistics.

In June 2016, the Russian regulator Rostechnadzor granted a construction license for the first unit of Kursk-II. It was suggested that in 2017, 16.5 billion rubles (US$274 million) was allocated for construction,[1112] with completion expected in 2022.[1113] The construction of the reactor started in April 2018, and its completion is planned for late 2023.[1114] This could be a particularly important project, as it would be the first of the latest Russian design, the VVER-TOI (VVER-V-510), which is said to be a 1200 MW, Generation III+ design and destined for export.

In August 2016, a Government decree called for the construction of an additional 11 reactors by 2030, which includes two new fast breeder reactors, a VVER600 at Kola and seven new VVER-TOI units at Kola, Smolensk, Nizhny Novgorod, Kostrom and Tatar.[1115] With the anticipated closures of reactors this is likely to mean that the installed capacity would be around 30 GW by 2030. It is unclear how even this development plan will be funded. The budget for construction of new reactors is expected to be in 2018, 2019 and 2020, modest 15.7 billion rubles (US$250 million), 16.6 billion rubles (US$260 million) and 17.7 billion rubles (US$280 million) respectively.[1116]

1109 - NTI, "Floating Nuclear Reactors Could Fall Prey to Terrorists, Experts Say", 13 August 2010, see http://www.nti.org/gsn/article/floating-nuclear-reactors-could-fall-prey-to-terrorists-experts-say/, accessed 1 May 2018.

1110 - Rosatom, "Leningrad NPP: Unit 1 with VVER-1200 connected to the national grid", (Press Release), 12 March 2018, see http://www.rosatom.ru/en/press-centre/news/leningrad-npp-unit-1-with-vver-1200-connected-to-the-national-grid/, accessed 30 April 2018.

1111 - *NEI*, "Russia's Rostov 4 begins commercial operation", 5 February 2018, see http://www.neimagazine.com/news/newsrussias-rostov-4-begins-commercial-operation-6046074/, accessed 1 May 2018.

1112 - Tatiana Kanunnikova, "Rosenergoatom invests $274m in building Kursk NPP this year", *Construction.RU*, 12 January 2017, see http://russianconstruction.com/news-1/26133-rosenergoatom-invests-274m-in-building-kursk-npp-this-year.html, accessed 1 May 2018.

1113 - *NIW*, "Briefs - Russia", 10 July 2017.

1114 - *NEI*, "Russia to start building Kursk-II in first half of 2018", 23 January 2018, see http://www.neimagazine.com/news/newsrussia-to-start-building-kursk-ii-in-first-half-of-2018-6033221/, accessed 1 May 2018.

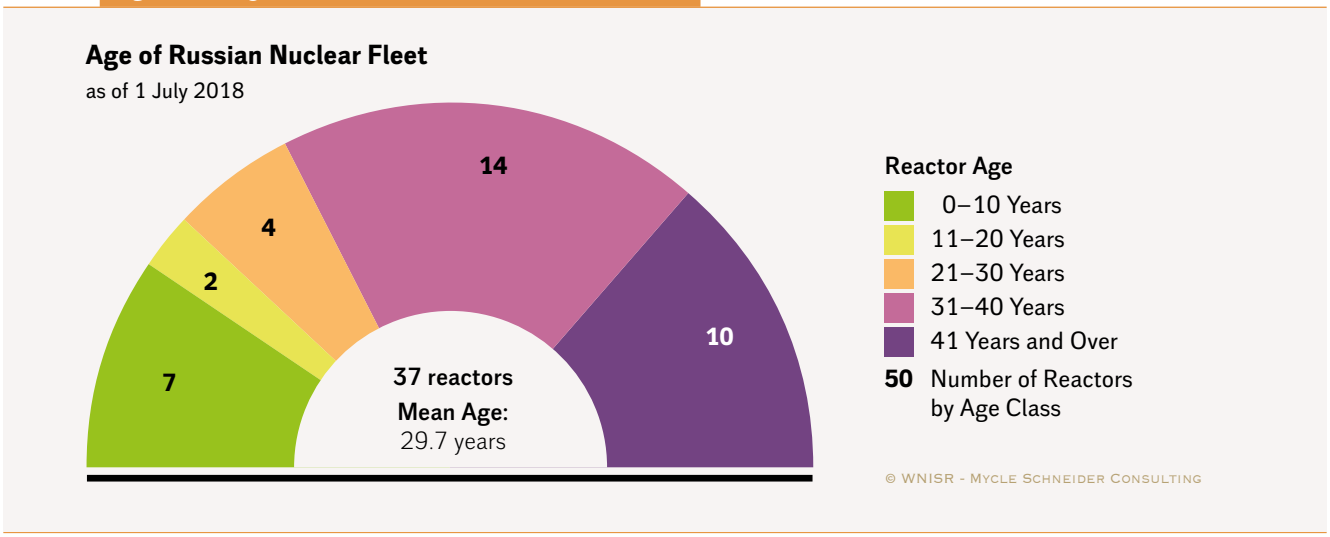
1115 - *WNN*, "Russia to build 11 new nuclear reactors by 2030", 10 August 2016, see http://www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html accessed 1 May 2018.

1116 - *NIW*, "Briefs - Russia", 22 September 2017.

Furthermore, the high cost of construction and its impact on the electricity market is threatening future projects. As a consequence, Rosatom has reluctantly provisionally agreed to postpone by a year the launch of its next two VVERs, so that the wholesale market can more easily absorb another round of price increases. A previously agreed arrangement to encourage investment in power generation enables investors to earn a 10.5 percent return over a 20-year period. This can have a significant impact on the local electricity market. Following the completion of the 880 MW fast reactor in the Urals and a VVER-1200 in southern Russia, the wholesale price of electricity increased by 15-20 percent compared to before the two units. While the Energy Consumers Association has estimated on average the electricity tariff will increase by 18 percent per year if the next four reactors under construction are completed by the end of the decade.[1117]

According to the International Atomic Energy Agency (IAEA), Russia has closed six power generating reactors: Obninsk-1, Beloyarsk-1 and -2, and Novovoronezh-1-3. The average age of the Russian reactor fleet is now 29.7 years, with over a quarter of its reactors being 41 years or more (see Figure 50). Therefore a key issue for the industry is how to manage its aging units.

Figure 50 | Age Distribution of the Russian Reactor Fleet



Sources: WNISR2018 with IAEA-PRIS

In the case of Russia's fleet, the operating age is in fact slightly misleading, as many units had excessively long construction times, in other words, the technology is already "old" before the reactors start up. Of the seven units that are less than 10 years old, five took more than 25 years to be completed.

There are mainly three classes of reactors in operation: the RBMK (a graphite-moderated reactor of the Chernobyl type), the VVER-440, and the VVER-1000. Both the RBMKs and VVER440 have been granted a 15-year life extension to enable them to operate for 45 years, although there are plans to extend this in some cases to 60 years[1118], while the VVER-1000s are expected to work for up to 50 years. According to the Norwegian NGO Bellona, life extensions

1117 - Gary Peach, "Newbuild Rollout Impacts Large Energy Users", *NIW*, 2 March 2018.

1118 - *NEI*, "Russia permanently closes Novovoronezh 3", 4 January 2017, see http://www.neimagazine.com/news/newsrussia-permanently-closes-novovoronezh-3-5709099/, accessed 1 May 2018.

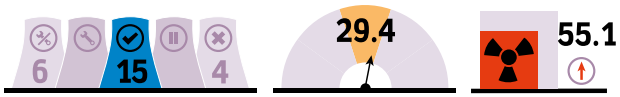
have been granted without the necessary environmental impact assessments, which has both, lead to protests but also makes the life extensions "something of a legal grey area".[1119]

Russia is an aggressive exporter of nuclear power, with, according to Rosatom, 33 separate projects although it only lists; Bangladesh (2 reactors at Rooppur); Belarus (2 reactors at Ostrovets); China (one reactor at Tianwan); Egypt (4 reactors at El Dabaa); Finland (1 reactor at Hanhikivi); Hungary (2 reactors at Paks); India (4 reactors at Kudankulam); Iran (1 reactor); Turkey (4 reactors).[1120] Of these, only seven are "under construction". (See Annex 9 for details).

The past 12 months represent a successful year for Russian exports with the start of construction of the first reactors in Turkey, Kudankulam-3 and -4 in India and Rooppur-1 in Bangladesh, as well as the signature of a US$30 billion deal to supply four VVER-1200s to Egypt.[1121] In June 2018, Rosatom signed a further agreement with CNNC. The deal was said to be for the supply of four VVER 1200 reactors—two for Tainwan and two at Xudapu. The agreement is said to also include the supply of equipment, fuel and services to the pilot CFR-600 fast-reactor project at Xiapu in Fujian.[1122] However, while many other projects are still to be officially launched and therefore may not come to fruition, the order book currently still puts Rosatom as the world's largest exporter. Rosatom claims to have an order book that exceeds US$133 billion, with 67 percent of the world market for nuclear power plant construction abroad.[1123]

A large part of the funding for these projects comes from Russia's Wealth Funds. However, these are also being used for stabilizing the Russian economy as a result of the lower oil and gas prices, the falling value of the ruble, and ongoing sanctions. The credit-rating agencies reflect more recent developments in the Russian economy, noting rising oil price and currency stability. In February 2018, Standard and Poor's raised the credit rating of JSC Atomic Energy Power Corporation (short name is Atomenergoprom, part of ROSATOM) from BB+ (junk) one notch up to investment rating BBB-. The positive impact on the credit capabilities of the company echoes the rise in credit-rating of the Russian Federation.[1124]

Ukraine



Ukraine has 15 operating reactors, two of the VVER440 design and the rest VVER-1000s. They provided 80.4 TWh or 55.1 percent of power in 2017, a significant increase over the past few years. Twelve out of the country's 15 reactors were completed in the late 1970s and 1980s and had an original design life of thirty years. Ukraine carries out a safety upgrade program for all its 15 reactors, estimated to cost €1.45 billion (US$1.62 billion) in total, of which the European Bank for Reconstruction and Development (EBRD) and EURATOM will contribute €600 mil-

1119 - Nils Bohmer, et.al., "Russian nuclear power–2017—Updated as of 30.05.2017", Bellona, 30 May 2017, see http://network.bellona.org/content/uploads/sites/3/2017/05/2017-Russian-nuclear-power-NO-ISBN.pdf, accessed 1 May 2018.

1120 - Rosatom, "Projects", Undated, see http://www.rosatom.ru/en/investors/projects/, accessed 1 May 2018.

1121 - Phil Chaffee, "Putin-Erdogan Relationship Key to Akkuyu Progress", *NIW*, 6 April 2018.

1122 - *NIW*, "Rosatom-CNNC Ink Deal Package of Historic Proportion", 8 June 2018.

1123 - Rosatom, "ROSATOM plans to expand nuclear construction abroad", 3 July 2018, see http://www.rosatom.ru/en/press-centre/news/rosatom-plans-to-expand-nuclear-construction-abroad-/ accessed 5 July 2018.

1124 - Rosatom, "Rating Agency Standard & Poor's raised the credit rating of Atomenergoprom from BB+ up to BBB-", 28 February 2018, see http://www.rosatom.ru/en/press-centre/news/rating-agency-standard-poor-s-raised-the-credit-rating-of-atomenergoprom-from-vv-up-to-vvv/, accessed 27 March 2018.

lion between them (US$670 million). The nuclear operator has proposed to extend lifetimes of the reactors for another 20 years. The proposal was accepted and now it is a core element of the nuclear strategy approved by the government. The decision for lifetime extension has resulted in controversy around the EBRD and EURATOM loans, because these did not foresee any life-time extension.

To date, two nuclear reactors at Rivne have been granted a lifetime extension of 20 years, two units at South Ukraine for 10 years, three units at Zaporizhzhya NPP for 10 years.[1125] International firms, including Westinghouse[1126] and Toshiba[1127] are to upgrade and extend the lives of the current reactors. The International Atomic Energy Agency (IAEA) completed a Pre-SALTO (Safety Aspects of Long-Term Operation) peer review mission at the third unit at the South Ukraine plant in April 2018 and concluded that "plant has made progress in the field of ageing management" but noted that it had only "initiated many activities to prepare for safe 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".[1128]

The lifetime extension of Rivne-1 and -2 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 its decision to prolong the lifetime of these VVER-440 reactors after their technical lifetime of 30 years.[1129] Environmental groups in Ukraine have called upon European institutions to stop the support for "risky" life extension programs.[1130] In April 2017, the Ukrainian Ministry of Environment sent official notification to neighboring countries on the start of the EIA for the lifetime extension of South Ukraine and at Zaporizhzhya.[1131]

Two reactors, Khmelnitsky-3 and -4, are officially under construction, but WNISR pulled them from the list. Building work started in 1986 and 1987 but stopped in 1990. In February 2011, Russia and Ukraine signed an intergovernmental agreement to complete the reactors, and in 2012, the Ukrainian Parliament adopted legislation to create a framework to finance the project, with 80 percent of the funds to be coming from Russia. However, in September 2015, the Ukrainian Parliament voted to cancel the project with Deputy Energy Minister Alexander Svetelik blaming Russia for "failing to fulfill the obligation under the deal", and saying that an "alternative

1125 - Uatom, "ZNPP Unit 3 Lifetime Extended", 3 November 2017, see http://uatom.org/index.php/en/2017/11/03/znpp-unit-3-lifetime-extended/, accessed 1 May 2018.

1126 - Gary Peach, "Ukraine", *NIW*, 15 September 2017.

1127 - *NEI*, "Ukraine plans nuclear expansion", 26 October 2017, see http://www.neimagazine.com/news/newsukraine-plans-nuclear-expansion-5957453/ accessed 1 May 2018.

1128 - IAEA, "IAEA Concludes Long-Term Operational Safety Review at South Ukraine Nuclear Power Plant", 25 April 2018, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-south-ukraine-nuclear-power-plant accessed 27 April 2018.

1129 - UNECE, "EIA/IC/CI/4 Ukraine", United Nations Economic Commission for Europe, Undated, see http://www.unece.org/environmental-policy/conventions/environmental-assessment/areas-of-work/review-of-compliance/committee-initiative/eiaicci4-ukraine.html, accessed 1 May 2018.

1130 - 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 1 May 2018.

1131 - Resource and Analysis Center "Society and Environment", "Ukraine starts transboundary environmental impact assessment for nuclear power plants", 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 1 May 2018.

partner" would be sought.[1132] In January 2017, the Russian Government confirmed that the 2011 agreement on the completion of the units had been cancelled.[1133] Subsequently, Skoda JS has been appointed as the main supplier for the completion of the reactors and an EIA procedure has begun.[1134]

In August 2017, the Government adopted a new energy strategy, which aims to maintain the current level of nuclear in the power mix, 50 percent up to 2035. While at the same time to half the level of energy intensity in the economy and increase the contribution of renewables to electricity to 25 percent (excluding hydro with 13 percent).[1135]

Proposals are now being developed to introduce direct connection from Khmelnitsky-2 to the European market. The Ukraine-EU Energy Bridge project, with an estimated cost of €243 million (US$290 million), could 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 Polenergia International, and EDF Trading. In October 2017, the Ukrainian Prime Minister further supported the energy bridge and said should the project proceed electricity sales from unit 2 would enable the restart of construction at the 3rd and 4th units in 2021.[1136]

1132 - Ed Adamczyk, "Ukraine scraps nuclear reactor deal with Russia", *UPI*, 16 September 2015, seehttps://www.upi.com/Top_News/World-News/2015/09/16/Ukraine-scraps-nuclear-reactor-deal-with-Russia/9811442413199/ accessed 1 May 2018.

1133 - *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 1 May 2018.

1134 - Energoatom, "Notice for the Environmental Impact Assessment for Khmelnisky 3 and 4", 2017, see http://eia.menr.gov.ua/uploads/documents/332/reports/10f33f0f9340fb1cd06c16c7bcc24950.pdf, accessed 2 May 2018.

1135 - *NEI*, "Ukraine reveals new energy strategy", 28 August 2017, see http://www.neimagazine.com/news/newsukraine-reveals-new-energy-strategy-5910630/ accessed 1 May 2018.

1136 - *NIW*, "Briefs—Ukraine", 20 October 2017.

ANNEX 2
STATUS OF CHINESE NUCLEAR REACTOR FLEET

Table 17 | Chinese Nuclear Reactors in Operation as of 1 July 2018

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
Changjiang-1	CNP-600	601	25/04/2010	07/11/2015	25/12/2015
Changjiang-2	CNP-600	601	21/11/2010	20/06/2016	12/08/2016
Daya Bay-1	M310	944	07/08/1987	31/08/1993	01/02/1994
Daya Bay-2	M310	944	07/04/1988	07/02/1994	06/05/1994
Fangchenggang-1	CPR-1000	1000	30/07/2010	25/10/2015	01/01/2016
Fangchenggang-2	CPR-1000	1000	23/12/2010	15/07/2016	01/10/2016
Fangjiashan-1	CPR-1000	1012	26/12/2008	04/11/2014	15/12/2014
Fangjiashan-2	CPR-1000	1012	17/07/2009	12/01/2015	12/02/2015
Fuqing-1	CPR-1000	1000	21/11/2008	20/08/2014	22/11/2014
Fuqing-2	CPR-1000	1000	17/06/2009	06/08/2015	16/10/2015
Fuqing-3	CPR-1000	1000	31/12/2010	07/09/2016	24/10/2016
Fuqing-4	CPR-1000	1000	01/10/2012	29/07/2017	17/09/2017
Hongyanhe-1	CPR-1000	1061	18/08/2007	01/02/2013	06/06/2013
Hongyanhe-2	CPR-1000	1061	28/03/2008	23/11/2013	13/05/2014
Hongyanhe-3	CPR-1000	1061	07/03/2009	23/03/2015	16/08/2015
Hongyanhe-4	CPR-1000	1061	15/08/2009	01/04/2016	19/09/2016
Ling Ao-1	M310	950	15/05/1997	26/02/2002	28/05/2002
Ling Ao-2	M310	950	28/11/1997	15/12/2002	08/01/2003
Ling Ao-3	CPR-1000	1007	15/12/2005	15/07/2010	15/09/2010
Ling Ao-4	CPR-1000	1007	15/06/2006	03/05/2011	07/08/2011
Ningde-1	CPR-1000	1018	18/02/2008	28/12/2012	15/04/2009
Ningde-2	CPR-1000	1018	12/11/2008	04/01/2014	04/05/2014
Ningde-3	CPR-1000	1018	08/01/2010	21/03/2015	10/06/2015
Ningde-4	CPR-1000	1018	29/09/2010	29/03/2016	21/06/2016
Qinshan-1	CNP-300	298	20/03/1985	15/12/1991	01/04/1994
Qinshan 2-1	CNP-600	610	02/06/1996	06/02/2002	15/04/2002
Qinshan 2-2	CNP-600	610	01/04/1997	01/03/2004	03/05/2004
Qinshan 2-3	CNP-600	619	28/03/2006	01/08/2010	05/10/2010
Qinshan 2-4	CNP-600	619	28/01/2007	25/11/2011	30/12/2011
Qinshan 3-1	CANDU 6	677	08/06/1998	09/10/2002	31/12/2002
Qinshan 3-2	CANDU 6	677	25/09/1998	12/06/2003	24/07/2003

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
Sanmen-1	AP-1000	1000	19/04/2009	30/06/2018	
Taishan-1	EPR-1750	1660	28/10/2009	29/06/2018	
Tianwan-1	VVER V-428	990	20/10/1999	12/05/2006	17/05/2007
Tianwan-2	VVER V-428	990	20/10/2000	14/05/2007	16/08/2007
Tianwan-3	VVER V-428M	1060	22/12/2012	30/12/2017	14/02/2018
Yangjiang-1	CPR-1000	1000	16/12/2008	31/12/2013	25/03/2014
Yangjiang-2	CPR-1000	1000	04/06/2009	10/03/2015	05/06/2015
Yangjiang-3	CPR-1000	1000	15/11/2010	18/10/2015	01/01/2016
Yangjiang-4	CPR-1000	1000	17/11/2012	08/01/2017	15/03/2017
Yangjiang-5	ACPR-1000	1000	18/09/2013	23/05/2018	12/08/2018
Total Reactors in Operation: 41 Reactors / 38.1 GWe					

Sources: Various, compiled by WNISR2018

Table 18 | Chinese Nuclear Reactor in LTO

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
CEFR	BN-20	20	10/05/2000	21/07/2011	

Note

The China Experimental Fast Reactor (CEFR) is not primarily a power generating reactor. However, as it was connected to the grid in 2011 at about 40 percent power and achieved full power for 72 hours starting 18 December 2014[1137], it is included in the WNISR. According to one source in China, the reactor has not been operating since December 2014, as it is lacking fuel. There are also other sources pointing to fuel issues.[1138] In January 2017, an agreement entered into force, for Russian Rosatom's subsidiary TVEL fabricating fuel for CEFR in 2017 and 2018 for loading into the reactor in 2019.[1139] We have therefore decided to take it off the operational status and put it into Long-Term Outage (LTO) as of December 2014.

1137 - *Xinhua*, "China experimental fast reactor runs at full capacity", in *China Securities Journal, 19 December 2014, see* http://www.cs.com.cn/english/ei/201412/t20141219_4595461.html, accessed 28 May 2018.

1138 - Marl Hibbs, "Rethinking China's Fast Reactor", *Arms Control Wonk*, 17 February 2017, see https://www.armscontrolwonk.com/archive/1202830/rethinking-chinas-fast-reactor/, accessed 28 May 2018.

1139 - *NEI*, "Russia to supply more fuel for China's fast reactor", 5 January 2017, see http://www.neimagazine.com/news/newsrussia-to-supply-more-fuel-for-chinas-fast-reactor-5709961, accessed 28 May 2018.

ANNEX 3
STATUS OF JAPANESE NUCLEAR REACTOR FLEET

Table 19 | Status of Japanese Nuclear Reactor Fleet (as of 1 July 2018)

Operator	Reactor	MW	Startup Year	Age Years	Shutdown		NRA Compliance		Status
					Date[a] dd/mm/yy	Duration	Application dd/mm/yy	Approval[b] dd/mm/yy	
CHUBU	Hamaoka-3 (BWR)	1056	1987	31.4	29/11/10	7.6	15/06/15		LTO
	Hamaoka-4 (BWR)	1092	1993	25.4	13/05/11	7.1	14/02/14		LTO
	Hamaoka-5 (BWR)	1325	2004	14.2	14/05/11	7.1			LTO
CHUGOKU	Shimane-2 (BWR)	789	1988	30	27/01/12	6.4	25/12/13		LTO
HEPCO	Tomari-1 (PWR)	550	1988	29.6	22/04/11	7.2	08/07/13		LTO
	Tomari-2 (PWR)	550	1990	27.8	26/08/11	6.8	08/07/13		LTO
	Tomari-3 (PWR)	866	2009	8.6	05/05/12	6.2	08/07/13		LTO
HOKURIKU	Shika-1 (BWR)	505	1993	25.5	01/03/11	7.3			LTO
	Shika-2 (BWR)	1108	2005	13	11/03/11	7.3	12/08/14		LTO
JAPCO	Tokai-2 (BWR)	1060	1978	40.3	21/05/11	7.1	20/05/14	July 2018[c]	LTO
	Tsuruga-2 (PWR)	1108	1986	32	29/08/11	6.8	05/11/15		LTO
KEPCO	Mihama-3 (PWR)	780	1976	42.4	14/05/11	7.1	17/03/15	16/11/16	LTO
	Ohi-3 (PWR)	1127	1991	27.1	02/09/13	(4.5)	08/07/13	01/09/17	Restarted 16/03/18
	Ohi-4 (PWR)	1127	1992	26	15/09/13	(4.5)	08/07/13	01/09/17	Restarted 11/05/18
	Takahama-1 (PWR)	780	1974	44.3	10/01/11	7.5	17/03/15	20/04/16[d]	LTO
	Takahama-2 (PWR)	780	1975	43.4	25/11/11	6.6	17/03/15	20/04/16	LTO
	Takahama-3 (PWR)	830	1984	34.1	20/02/12	(3.9)e	08/07/13	09/10/15	Restarted 9/06/17e
	Takahama-4 (PWR)	830	1984	33.7	21/07/11	(5.8)	08/07/13	09/10/15	Restarted 22/05/17
KYUSHU	Genkai-2 (PWR)	529	1980	38.1	29/01/11	7.4			LTO
	Genkai-3 (PWR)	1127	1993	25	11/12/10	(7.3)	12/07/13	14/09/17	Restarted 23/03/18
	Genkai-4 (PWR)	1127	1996	21.6	25/12/11	(6.5)	12/07/13	14/09/17	Restarted 20/06/18
	Sendai-1 (PWR)	846	1983	34.8	10/05/11	(4.3)	08/07/13	27/05/15	Restarted 14/08/15
	Sendai-2 (PWR)	846	1985	33.2	01/09/11	(4.1)	08/07/13	27/05/15	Restarted 15/10/15
SHIKOKU	Ikata-3 (PWR)	846	1994	24.3	29/04/11	(5.3)	08/07/13	19/04/16	Restartedf 15/08/16[f]

Operator	Reactor	MW	Startup Year	Age Years	Shutdown		NRA Compliance		Status
					Date[a] dd/mm/yy	Duration	Application dd/mm/yy	Approval[b] dd/mm/yy	
TEPCO	Kashiwazaki Kariwa-1 (BWR)	1067	1985	33.4	06/08/11	6.9			LTO
	Kashiwazaki Kariwa-2 (BWR)	1067	1990	28.4	19/02/07	11.4			LTO
	Kashiwazaki Kariwa-3 (BWR)	1067	1992	25.6	16/07/07	11			LTO
	Kashiwazaki Kariwa-4 (BWR)	1067	1993	24.5	16/07/07	11			LTO
	Kashiwazaki Kariwa-5 (BWR)	1067	1989	28.8	25/01/12	6.4			LTO
	Kashiwazaki Kariwa-6 (BWR)	1315	1996	22.4	26/03/12	6.3	27/9/13[g]	27/12/17	LTO
	Kashiwazaki Kariwa-7 (BWR)	1315	1996	21.5	23/08/11	6.9	27/09/13	27/12/17	LTO
	Fukushima Daini-1 (BWR)	1067	1981	29.6	11/03/11	7.3			Shutdown[h]
	Fukushima Daini-2 (BWR)	1067	1983	27.7	11/03/11	7.3			Shutdown
	Fukushima Daini-3 (BWR)	1067	1984	26.2	11/03/11	7.3			Shutdown
	Fukushima Daini-4 (BWR)	1067	1986	24.2	11/03/11	7.3			Shutdown
TOHOKU	Higashi Dori-1 (BWR)	1067	2005	12.8	06/02/11	7.4	20/06/14		LTO
	Onagawa-1 (BWR)	498	1983	34.6	10/09/11	6.8			LTO
	Onagawa-2 (BWR)	796	1994	23.5	06/11/10	7.6	27/12/13		LTO
	Onagawa-3 (BWR)	796	2001	17.1	10/09/11	6.8			LTO

Sources: JAIF, Japan Nuclear Safety Institute, compiled by WNISR, 2018

Notes

a - The shutdown dates are from JAIF, "Nuclear Power Plants in Japan - In operation and under construction", Japan Atomic Industrial Forum, as of 10 June 2014, **see** http://www.jaif.or.jp/english/news_images/pdf/ENGNEWS02_1402531967P.pdf, accessed 13 June 2014.

b - Gray dates refer to the first step (Permission for change in reactor installation license). All others indicate final agreement of the 3-step conformity review.

c - JAIF, "Draft Report: Tokai-2 NPP Complies with New Regulatory Standards", 4 July 2018, see http://www.jaif.or.jp/en/nra-draft-report-tokai-2-npp-complies-with-new-regulatory-standards/, accessed 6 July 2018.

d - For both Takahama-1 and -2, the first two steps of the conformity review were achieved on 20 June 2016. On 20 June 2016, the Nuclear Regulation Authority (NRA) also granted KEPCO approval of extension of operation for 20 years. 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.

e - 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 this first restart.

f - On 13 December 2017, the Hiroshima High Court ruled in favor of a citizen lawsuit and issued an injunction against operation of the Ikata-3 reactor which remains in place until September 2018.

g - On 16 June 2017 TEPCO re-filed its application with the NRA to confirm compliance with safety requirements for Kashiwazaki Kariwa-6 and -7. The NRA had requested resubmission in February 2017.

h - All 4 Fukushima Daini reactors are considered as permanently shutdown by WNISR since March 2011. However, it is only in June 2018 that TEPCO announced that they would consider decommissioning but are not at this point considered as "officially shutdown".

See TEPCO, "Dialogue with Fukushima governor about Fukushima Daini Nuclear Power Station", Press Release, 14 June 2018, see http://www.tepco.co.jp/en/announcements/2018/1497224_15434.html, accessed 14 June 2018.

Age for those reactors is age at shutdown date according to WNISR classification.

ANNEX 4
INNOVATIONS FOR NUCLEAR RESCUE SUBSIDIES
A STATE-BY-STATE OVERVIEW

As reported in WNISR2017, the leading example of how utilities have tried and succeeded in obtaining substantial extra revenues to maintain profitability of their nuclear fleet has been in the state of **Illinois.** In the past few years, some of the plants owned by Exelon, the largest nuclear operator in the U.S., have failed to clear the capacity market auctions, especially in the Pennsylvania-New Jersey-Maryland Interconnection (PJM). The story is similar in the Midcontinent Independent System Operator (MISO) interconnection, which covers part of Illinois and 14 other states.

The capacity market involves power plants committing to having a certain amount of generating capacity ready for delivering power upon demand and receiving a payment for that capacity. In the capacity market auctions, the plants that are ready to commit dispatchable power at the lowest cost are chosen first. Once the projected demand for the future has been met, the plants that are offering to supply power at higher costs are said to have not cleared the market.

The response of utilities with nuclear plants to their inability to clear auctions has been to blame the structure of the markets rather than their own high costs. Joseph Dominguez, Exelon's senior vice president for governmental and regulatory affairs and public policy, told *Nuclear Engineering International* (*NEI*) that "(...) the market does not sufficiently recognize the significant value that nuclear plants provide in terms of reliability and environmental benefits".[1140] Independent assessments do not support that claim, which has so far taken at least 14 forms.[1141]

In July 2015, the Federal Energy Regulatory Commission (FERC) approved PJM's (Pennsylvania-New Jersey-Maryland Interconnection LLC) restructuring proposals that would allow it to increase payments to utilities that can more reliably deliver power. Despite higher prices, in August 2015, Exelon announced that three of its nuclear plants, "Oyster Creek, Quad Cities and Three Mile Island [...] did not clear in the PJM capacity auction for the 2018-19 planning year".[1142] The company also announced that "a portion of the Byron nuclear plant's capacity did not clear the auction".[1143]

1140 - *NEI*, "Exelon on the 2014 PJM Capacity Market Auction", interview with Joseph Dominguez, Senior Vice President for Governmental and Regulatory Affairs and Public Policy, Exelon Corp., 12 June 2014, see https://www.nei.org/News-Media/News/News-Archives/Exelon-on-the-2014-PJM-Capacity-Market-Auction, accessed 23 May 2017.

1141 - Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journal*, Vol.30, Issue 6, July 2017, see http://dx.doi.org/10.1016/j.tej.2017.06.002, accessed 6 August 2017.

1142 - Exelon Corporation, "Exelon Announces Outcome of 2018-19 PJM Capacity Auction", *Business Wire*, 24 August 2015, see http://www.businesswire.com/news/home/20150824005330/en/Exelon-Announces- Outcome-2018-19-PJM-Capacity-Auction, accessed 23 May 2017.

1143 - Sonal Patel, "Two Exelon Nuclear Plants Fail to Clear PJM Auction", *POWER Magazine*, 25 May 2016, see http://www.powermag.com/two-exelon-nuclear-plants-fail-to-clear-pjm-auction/, accessed 23 May 2017.

In 2016, Exelon teamed up with subsidiary Commonwealth Edison Company or ComEd, and proposed "a larger bill that would make sweeping changes to the state's energy system" and add "a surcharge onto electricity bills that would make the nuclear plants profitable".[1144] Analysts estimated the proposed "changes would amount to a total rate hike of US$7.7 billion over 10 years that would be paid by government, businesses and consumers... [and] that Exelon and ComEd would reap US$1 billion in guaranteed profits from the plan over a decade", including "a subsidy of as much as US$2.6 billion over that time".[1145] While on the one hand, Exelon was seeking subsidies from government and customers, on the other hand, it has been presenting itself as profitable to Wall Street.[1146]

Subsequently a provision of the Illinois Future Energy Jobs Act passed the state legislature on 7 December 2016, establishing a Zero Emissions Credits (ZEC) program that provided financial support to certain in-state nuclear generators that have become uncompetitive in wholesale markets. The ZEC price may be above current rates to provide financial support to a power generator. Through this program, the Exelon- owned Clinton and Quad Cities nuclear plants would be eligible for ZECs. On 14 February 2017, the Electric Power Supply Association (EPSA) filed a complaint in the U.S. District Court of the Northern District of Illinois opposing the proposed ZEC's for Exelon, stating that "bailing out uneconomic power plants is a bad deal for Illinois ratepayers, who will see their electric bills go up across the state".[1147]

On 17 July 2017, the Illinois District Court agreed with Exelon's argument and ruled the state has authority to subsidize nuclear generation, and that the ZEC program did not violate the implicit authority granted by the Constitution, allowing the federal government the right to regulate interstate trade. An appeal was immediately filed by petitioners, with one of them representing NRG Energy stating: "If upheld, the Illinois decision would effectively strip FERC of its authority to regulate wholesale markets, would harm ratepayers, and threaten FERC's ability to drive investment in energy infrastructure".[1148]

The availability of the ZEC program in Illinois led Exelon in 2017 to reverse its decision to permanently shut the Clinton nuclear plant scheduled for 1 June 2017 and its two-unit Quad Cities on 1 June 2018. Exelon had filed an application with the Nuclear Regulatory Commission (NRC) for termination of its operating license for Clinton, subsequently withdrawn.[1149] The Clinton reactor is predicted to be operating at a profit of 3.7 US$/MWh through 2017-2019; whereas the Quad Cities plant is expected to operate at a loss of 4.3 US$/MWh over the same period.

1144 - Kim Geiger, "Exelon makes another try for energy changes that critics call bailout", *Chicago Tribune*, 27 May 2016, see http://www.chicagotribune.com/news/local/politics/ct-illinois-com-ed-exelon-bill-20160527-story.html, accessed 23 May 2017.

1145 - Ibidem.

1146 - Steve Daniels, "Exelon tells Wall St. one thing about profits while peddling a different tale in Springfield", *Crain's Chicago Business*, 30 April 2016, see http://www.chicagobusiness.com/article/20160430/ISSUE01/304309995/exelon-tells-wall-st-one-thing-about-profits-while-peddling-a-different-tale-in-springfield, accessed 23 May 2017.

1147 - Keith Goldberg, "Nuke Plant Subsidies Flout FERC, Power Cos. Say", *Law360*, 15 February 2017, see https://www.law360.com/articles/892374/ill-nuke-plant-subsidies-flout-ferc-power-cos-say, accessed 15 May 2017.

1148 - United States District Court For The Northern District Of Illinois Eastern Division, 14 July 2018, see https://statepowerproject.files.wordpress.com/2017/02/il-zec-decision.pdf, accessed 9 May 2018; and *Utility Dive*, "Updated: Federal judge dismisses challenge to Illinois nuke subsidies", 17 July 2017, see https://www.utilitydive.com/news/updated-federal-judge-dismisses-challenge-to-illinois-nuke-subsidies/447202/, accessed 9 May 2018.

1149 - U.S.NRC, "[Docket No. 50–461; NRC–2016–0207] Exelon Generation Company LLC; Clinton Power Station, Unit 1—License amendment application; withdrawal by applicant", Federal Register Vol.82, No.4, 6 January 2017, see https://www.federalregister.gov/documents/2017/01/06/2017-00045/exelon-generation-company-llc-clinton-power-station-unit-1, accessed 15 May 2017.

On 25 January 2018, the Illinois Commerce Commission announced that Exelon's Quad Cities and Clinton reactors had successfully been selected for ZEC credits, which in the first delivery year 1 June 2017–31 May 2018, the ZEC price paid to each facility will equal US$16.50/MWh.[1150] This equates to a cumulative value over the expected life of the ZEC contracts, without any adjustments, of US$3.5 billion. Exelon reported that it expected US$150 million in ZEC revenue for the period June to December 2017.

Meanwhile the legal challenge to the nuclear ZEC's continues, with appeal oral hearings held at the U.S. Court of Appeals for the 7th Circuit in January 2018.[1151] As of 1 July 2018 a decision remains pending.

> *"Unit 1 is unprofitable and has lost more than US$300 million over the past five years despite being one of Exelon's best-performing plants"*

The future of Three Mile Island (TMI) in **Pennsylvania** appears increasingly to hang in the balance, with Exelon and industry supporters pushing for nuclear supporting ZEC in the Pennsylvania legislature, but which have yet to materialize as of 1 July 2018.[1152] On 30 May 2017, Exelon announced that it had notified the NRC of plans to permanently shut down TMI in September 2019.[1153] The decision included terminating capital investment projects required for long-term operation of TMI and cancelling 2019 fuel purchases and outage planning. Exelon made explicit the reasons for closure: "Unit 1 is unprofitable and has lost more than US$300 million over the past five years despite being one of Exelon's best-performing plants... The energy market in PJM has not adapted to the evolution of the fleet, which has caused the devaluation of resources."[1154]

In May 2017, Exelon had announced that the TMI and Quad Cities reactors had not cleared the auction for the period 2020-21.[1155] It is the third straight year where TMI did not clear PJM base residual auctions. The Pennsylvania legislature as of 1 July 2018 had not passed specific legislation as sought by Exelon (including nuclear into the state's renewable portfolio standard or approval of a ZEC that would provide additional financial assistance to Exelon's nuclear plants) though it still remains possible that the decision to shut down TMI in 2019 will be reversed.[1156] The closure of TMI and Beaver Valley unit 1 and 2 (planned for May and October 2021[1157],

1150 - Illinois Commerce Commission, "Public Notice of Successful Bidders and Average Prices Illinois Power Agency January 2018 Procurement of Zero Emission Credits from Facilities Fueled by Nuclear Power", 25 January 2018, see https://www.ipa-energyrfp.com/?wpfb_dl=1450, accessed 9 May 2018.

1151 - Peter Maloney, "Federal appeals court hears arguments in Illinois ZEC case", *Utility Dive*, 5 January 2018, see https://www.utilitydive.com/news/federal-appeals-court-hears-arguments-in-illinois-zec-case/514107/, accessed 9 May 2018.

1152 - Ad Crable, "Three Mile Island nuclear plant again fails key power auction, decision whether to close 'to be made soon'", *LancasterOnline*, 24 May 2017, see http://lancasteronline.com/news/local/three-mile-island-nuclear-plant-again-fails-key-power-auction/article_e12d94f8-4080-11e7-8297-034697ee2fd0.html, accessed 24 May 2017.

1153 - Exelon, "Exelon To Retire Three Mile Island Generating Station in 2019", 30 May 2017, see http://www.exeloncorp.com/newsroom/exelon-to-retire-three-mile-island-generating-station-in-2019, accessed 9 May 2018.

1154 - *PennLive*, "Three Mile Island operator takes another step toward closing nuclear plant", 23 June 2017, http://www.pennlive.com/news/2017/06/three_mile_island_closing_nrc.html, accessed 9 May 2018.

1155 - Exelon, "Exelon Announces Outcome of 2020-2021 PJM Capacity Auction", Press Release, 24 May 2017, see http://www.exeloncorp.com/newsroom/pjm-auction-results-release-2017, accessed 24 May 2017.

1156 - *Chicago Tribune*, "Column: In another sign of the end of nuclear power, shutdown looms for Exelon's Three Mile Island", 31 May 2017, see http://www.chicagotribune.com/business/columnists/ct-hiltzik-three-mile-island-20170531-story.html, accessed 9 May 2018.

1157 - *PA Environment Digest*, "FirstEnergy Files Letter With NRC Affirming Plans To Deactivate Beaver Valley, 2 Other Nuclear Power Plants", 4 April 2018, see http://www.paenvironmentdigest.com/newsletter/default.asp?NewsletterArticleID=43293&SubjectID, accessed 20 May 2018.

owned by FirstEnergy) would represent 25 percent of the state's nuclear generating capacity, which is the second highest in the U.S., after Illinois.

FirstEnergy, in advance of bankruptcy filings, warned in March 2018 that it would close its two reactors at Beaver Valley in May and October 2021, unless state and federal financial support was forthcoming. FirstEnergy submitted a request 29 March 2018 to U.S. Energy Secretary Rick Perry seeking an emergency order to be issued to the PJM for immediate negotiations to secure the long-term capacity of certain nuclear and coal-fired plants in the region and to compensate their owners "for the full benefits they provide to energy markets and the public at large, including fuel security and diversity."[1158] In April 2018, First Energy filed official notification with the Nuclear Regulatory Commission (NRC) of its bankruptcy and planned closure of Beaver Valley, as well as the two reactors at Davis Besse and Perry in Ohio.[1159] First Energy noted: "We are actively seeking policy solutions at the state and federal level as an alternative to retiring these plants, which we believe still have a crucial role to play in the reliability and resilience of our regional grid.,"[1160] but that "short of significant market changes … right now, we have nothing in front of us that allows us to rescind that deactivation notice."[1161]

In **New Jersey**, on 9 January 2018, legislation was reintroduced to the Senate, after failing in the previous legislative session, to create a "nuclear diversity certificate" program and direct the state's Board of Public Utilities for a monthly surcharge on customer electric bills to be paid to nuclear plants designated by the board. The Public Service Enterprise Group (PSEG) utility nuclear plants Salem units 1&2 and Hope Creek, would be direct beneficiaries of US$300 million per year. Meanwhile, in evidence to the legislature in February 2018, the PJM Power Providers Group P3),[1162] noted that Oyster Creek and TMI-1 are currently the only two nuclear plants on PJM's deactivation list and PJM identified no reliability impacts associated with either unit's closure.[1163] The P3 in opposition to efforts to establish a Zero Emission Credit (ZEC) for nuclear plants in New Jersey made its position clear:

> P3 remains opposed to any legislative efforts that interfere with the competitive, regional, federally regulated, wholesale markets by providing out of market support for selected resources. Senate Bill 877 and Assembly Bill 2850 ("the ZEC Bills") not only undermine the

1158 - *PA Environment Digest*, "FirstEnergy Seeks Emergency Federal Order To Avert Shutdown Of Nuclear, Coal Power Plants", 29 March 2018, see http://www.paenvironmentdigest.com/newsletter/default.asp?NewsletterArticleID=42966, accessed 20 May 2018; and Dean Murphy, Mark Berkman, "Impacts of Announced Nuclear Retirements in Ohio and Pennsylvania", Brattle Group, April 2018, see https://d3n8a8pro7vhmx.cloudfront.net/nuclearmatters/pages/313/attachments/original/1523484599/Impacts_of_Premature_Nuclear_Retirements_in_Ohio_and_Pennsylvania..pdf?1523484599, accessed 20 May 2018.

1159 - U.S.NRC, "Acknowledgment Of Firstenergy Solutions, Firstenergy Nuclear Generation, And Firstenergy Nuclear Operating Company Bankruptcy Notification", 6 April 2018, see https://www.nrc.gov/docs/ML1809/ML18093B546.pdf, accessed 20 May 2018.

1160 - *PA Environment Digest*, "FirstEnergy Files Letter With NRC Affirming Plans To Deactivate Beaver Valley, 2 Other Nuclear Power Plants", 4 April 2018.

1161 - Nick Malawskey, "Clock ticks toward TMI shutdown", *PennLive*, 26 April 2018, see http://www.pennlive.com/news/2018/04/clock_ticks_toward_tmi_shutdow.html, accessed 20 May 2018.

1162 - P3 is a non-profit organization that supports the development of properly designed and well functioning markets in the PJM region. Combined, P3 members own over 84,000 megawatts of generation assets, produce enough power to supply over 20 million homes and employ over 40,000 people in the PJM region covering 13 states and the District of Columbia, see https://www.p3powergroup.com/sitecontent.cfm?page=about, accessed 9 May 2018.

1163 - PJM Power, "Testimony of the PJM Power Providers Group (P3)", Senate Bill 877, Assembly Bill 2850, New Jersey Senate Appropriations and Assembly Telecommunications and Utilities Committees, 22 February 2018, see https://www.p3powergroup.com/siteFiles/News/1757A0A61B967A2867F0A1ADE20C976E.pdf, accessed 9 May 2018.

> competitive market in New Jersey and the entire PJM region, they represent an ill-conceived giveaway that unnecessarily harms consumers.[1164]

In order to qualify for the New Jersey credits, nuclear plants will need to be licensed through 2030, which means the Oyster Creek reactor is not eligible, as it was granted a license renewal in 2009 to operate until 2029.[1165] Oyster Creek, the oldest reactor in the United States, remains on path for closure in September 2018.[1166]

On 12 April 2018, legislatures passed the ZEC bill, which will provide the financial aid to Salem and Hope Creek nuclear plants that PSEG were seeking.[1167] On 30 April 2018, it was made clear by PSEG CEO that the New Jersey ZEC's could also aid nuclear plants in Pennsylvania, specifically the Peach Bottom plant, of which PSEG is half owner, as well as Susquehanna (owned by Talen Energy) and Exelon's Limerick plants.[1168] On 23 May 2018, the Governor of New Jersey signed the ZEC bill. The legislation allows the two-unit Salem plant, in which PSEG has a 57-percent ownership stake and Exelon a 43-percent stake, and PSEG's fully owned Hope Creek reactor, to receive zero-emission certificate payments.[1169]

Another state where lobbying by the nuclear industry has brought them closer to financial assistance was **Connecticut**, where Dominion Energy operates the two reactors at Millstone. Earlier efforts in 2016 had failed.[1170] As a result, the Connecticut Senate passed legislation in 2016 that would have changed the market structure in the +state and would have protected Dominion's Millstone plant. However, the bill failed to come to the vote and "died" in Connecticut's House of Representatives.[1171]

On 7 November 2017, Governor Malloy passed the Senate Zero Carbon Procurement Act, which potentially would permit Dominion to sell its Millstone generation.[1172]

The Millstone nuclear plant was listed in 2017 as the most profitable in the U.S. through 2019, at US$14/MWh. Yet Dominion has attempted to use the threat of closure of Millstone as leverage to secure state support. In a study commissioned by the Stop the Millstone Payout coalition, a group composed of competitive energy companies NRG, Calpine and Dynegy and the

1164 - Ibidem.

1165 - U.S.NRC, "Oyster Creek Nuclear Generating Station—License Renewal Application", 14 April 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/oystercreek.html, accessed 9 May 2018.

1166 - Electric Light & Power, "Oyster Creek nuclear power plant owners file $1.4 billion closing plan", 1 June 2018, see https://www.elp.com/articles/2018/06/oyster-creek-nuclear-power-plant-owners-file-1-4-billion-closing-plan.html, accessed 12 July 2018.

1167 - Peter Key, "NJ Lawmakers Pass Nuke Subsidies, Boosted RPS", *RTO Insider*, 12 April 2018, see https://www.rtoinsider.com/nuclear-subsidies-new-jersey-zec-rps-90356/, accessed 9 May 2018.

1168 - Peter Key, "Izzo: Nukes Outside NJ Likely Eligible for State ZECs", *RTO Insider,* 30 April 2018, see https://www.rtoinsider.com/pseg-zecs-ralph-izzo-q1-2018-earnings-91640/, accessed 20 May 2018.

1169 - Scott DiSavino, "New Jersey governor signs nuclear power subsidy bill into law", *Reuters*, 24 May 2018, see https://www.reuters.com/article/us-new-jersey-pseg-exelon-nuclear/new-jersey-governor-signs-nuclear-subsidy-bill-into-law-idUSKCN1IO2RL, accessed 24 May 2018.

1170 - WNISR2017, and Mark Pazniokas, "Nuclear power's future in Connecticut is on the table", *The Connecticut Mirror*, 23 March 2016, see http://ctmirror.org/2016/03/23/nuclear-powers-future-in-connecticut-is-on-the-table/, accessed 25 May 2017; and Judy Benson, "Bill that would have protected Millstone from energy market dips dies in House", *The Day*, 6 May 2016, see http://www.theday.com/article/20160505/NWS01/160509539, accessed 23 May 2017.

1171 - Judy Benson, "Bill that would have protected Millstone from energy market dips dies in House", *The Day*, 6 May 2016, see http://www.theday.com/article/20160505/NWS01/160509539, accessed 23 May 2017.

1172 - EnerKnoll Research, "Connecticut Passes Bill Paving Way to Subsidize Dominion Nuclear Plant", 7 November 2018, see https://enerknol.com/wp-content/uploads/2017/11/EKR-AE-Visual-Primer-Connecticut-Nuclear-SubsidyBill-11-7-2017.pdf, accessed 20 May 2018.

Electric Power Supply Association (EPSA), challenged Dominion's claims. The study showed that state support for Millstone would cost ratepayers US$330 million per year, translating to a 15-20 percent increase in supply costs. Under ISO-New England rules, Millstone is currently obligated to provide capacity to the region through May 2021 and would have to pay to break those commitments.[1173] The report concludes that if Millstone were to close today, those penalties would amount to at least US$680 million – and would be closer to US$1 billion once other market obligations are factored in.

The Connecticut legislature draft market study, released in January 2018, concluded that the Millstone units will be profitable over the period 2021 through 2035.[1174] Under the base case assumptions, the profitability is expected to amount to a net present value of up to US$2,373 million in 2017. NRG Energy, opposed to Millstone being able to access the ZEC procurement, stated: "Giving an extremely profitable nuclear plant the same status as true renewables makes Dominion a winner and everyone else, especially ratepayers, losers."[1175]

In March 2018, the assessment by the State recommended that Millstone be permitted to sell its power on the open market through competitive bidding. "We think this is the right path forward and we are finding a way to do a procurement that is most protective to ratepayers," said commissioner of the State's Department of Energy (DOE) and Environmental Protection (DEEP).[1176]

In October 2015, Entergy Corporation announced that it would close down the Pilgrim nuclear plant in **Massachusetts** because the 43-year-old plant was "simply no longer financially viable" and that it had already informed ISO New England, the regional transmission organization that Pilgrim would not be part of the next electricity auction.[1177] In April 2016, Entergy announced the closing date of the plant as 31 May 2019.[1178] There is no indication that Entergy will reverse its decision on closure, with plans filed in March 2017 with the Nuclear Regulatory Commission (NRC) related to moving spent fuel from the reactors pool to dry storage.[1179] Meetings continued through 2017-2018 for the planned closure of Pilgrim as scheduled.[1180]

Meanwhile in **Michigan**, Entergy announced 28 September 2017 its decision to reverse closure plans for the Palisades nuclear plant, scheduled for October 2018, with the intention

1173 - Stop The Millstone Payout, "Amid New Data, Dominion's Closure Threats Face The $1 Billion Question Administrator", 11 October 2017, see http://www.stopthemillstonepayout.com/press-center/, accessed 19 May 2018.

1174 - Connecticut Department of Energy & Environmental Protection, "Connecticut Public Utilities Regulatory Authority Resource Assessment Of Millstone Pursuant To Executive Order No.59 And Public Act 17-3—Determination Pursuant To Public Act 17-3", January 2018, see http://www.ct.gov/deep/lib/deep/energy/e059/2018jan22_draft_report_and_determination.pdf, accessed 20 May 2018.

1175 - Scott DiSavino, "Connecticut says Dominion should show why nuclear plant needs subsidy", *Reuters*, 3 February 2018, see https://www.reuters.com/article/us-connecticut-nuclearpower-dominion-inc/connecticut-says-dominion-should-show-why-nuclear-plant-needs-subsidy-idUSKBN1FM2LP, accessed 20 May 2018.

1176 - *Post Chronicle*, "Report: Millstone power plant viable through 2035", 1 March 2018, see http://www.ctpostchronicle.com/news/report-millstone-power-plant-viable-through/article_2aa13439-19ea-5887-a7ca-23eb793f8525.html, accessed 20 May 2018.

1177 - *S&P Global*, "Entergy to shut Pilgrim nuclear power plant as early as 2017", Platts, 13 October 2015, see https://www.platts.ru/latest-news/electric-power/washington/entergy-to-shut-pilgrim-nuclear-power-plant-as-21284265, accessed 16 August 2018.

1178 - *WNN*, "Three more years for USA's Pilgrim plant", 15 April 2016, see http://www.world-nuclear-news.org/C-Three-more-years-for-USAs-Pilgrim-plant-1504167.html, accessed 15 April 2016.

1179 - Justin Saunders, "Entergy Takes Next Steps for Pilgrim Closure", *CapeCod.com*, 13 March 2017, see http://www.capecod.com/newscenter/entergy-takes-next-steps-for-pilgrim-closure/, accessed 23 May 2017.

1180 - *Cape Cod Times*, "Panel seeks to define state role in Pilgrim closure", 18 May 2018, see http://www.capecodtimes.com/news/20180518/panel-seeks-to-define-state-role-in-pilgrim-closure, accessed 20 May 2018.

to operate the plant until spring of 2022.[1181] The decision followed a September 2017 decision by Michigan Public Service Commission (MPSC) to award less money to underwrite a contract buyout agreement which had been agreed between Consumers Power (public utility in Michigan) and Entergy in 2016.[1182] The vote by MPSC effectively terminated the 2016 agreement, meaning that the existing power purchase agreement will continue until 2022.[1183] Entergy reported that the decision would be US$100-150 million cash positive for the utility. The single unit 850 MW Palisades reactor, which was connected to the grid in December 1971, has a license NRC extension to operate until 2031.[1184] The Palisades reactor, one of the oldest in the U.S. fleet, has long been under contention on safety grounds, specifically its extensive neutron radiation embrittlement of the Reactor Pressure Vessel (RPV), the most severe on record in the U.S.[1185]

In **New York State**, legal challenges continue in 2018 over the approval of Zero Emission Credits (ZECs) for the states nuclear plants. On 25 July 2017, the U.S. District Court of the Southern District of New York issued an order dismissing challenges led by the Coalition for Competitive Electricity against the New York state ZEC program established in 2016 by the New York Public Service Commission (NYPSC).[1186] The case made by the Coalition was that the NYPSC had failed to properly follow the State Administrative Procedure Act in developing the ZEC program as part of the state's Clean Energy Program that also provides credits to wind and solar power generators. With oral arguments heard in March 2018, the judgement in this case is expected within months to one year.[1187]

In January 2018, a New York state Supreme Court judge dismissed a motion by Exelon Generation and Entergy to summarily dismiss a lawsuit that challenges the state's ZEC program designed to provide financial assistance to four reactors in the state, FitzPatrick, Ginna, and Nine Mile Point-1 and -2.[1188] The lawsuit had been filed by a coalition of environmental and anti-nuclear groups. The case will now go to trial. The New York ZECs provide Exelon up to US$482.76 million in the 12 months through 31 March 2018, and the same for the year to March 2019 for the four units.

1181 - Entergy, "Entergy to Continue Operating Palisades Power Plant Until Spring 2022", Press Release, 28 September 2017, see http://www.palisadespower.com/entergy-to-continue-operating-palisades-power-plant-until-spring-2022/, accessed 20 May 2018.

1182 - Department of Licensing and Regulatory Affairs, "MPSC [Michigan Public Service Commission] cuts to $142 million amount Consumers Energy can use to buy out its Palisades power contract", MPSC, Press Release, 22 September 2017, see https://www.michigan.gov/mpsc/0,4639,7-159-16400_17280-447928--,00.html, accessed 20 May 2018.

1183 - Sonal Patel, "Entergy Gives Palisades Nuclear Plant Five More Years to Run", *POWER Magazine*, 28 September 2017, see http://www.powermag.com/entergy-gives-palisades-nuclear-plant-five-more-years-to-run/, accessed 20 May 2018.

1184 - Beyond Nuclear, "Beyond Nuclear warns about safety risks of operating Palisades till 2022", 28 September 2017, see http://www.beyondnuclear.org/safety/2017/9/28/beyond-nuclear-warns-about-safety-risks-of-operating-palisad.html, accessed 20 May 2018.

1185 - Beyond Nuclear, "Beyond Nuclear warns NRC against weakening RPV embrittlement/PTS safety regulations at Palisades", 30 October 2014, see http://www.beyondnuclear.org/safety/2014/10/30/beyond-nuclear-warns-nrc-against-weakening- rpv-embrittlement.html, accessed 20 May 2018..

1186 - Adrienne Thompson, Christopher Zentz, "Federal District Court Dismisses Challenges to New York ZEC Program", *Washington Energy*, 31 July 2017, see https://www.troutmansandersenergyreport.com/2017/07/federal-district-court-dismisses-challenges-new-york-zec-program/, accessed 20 May 2018.

1187 - *S&P Global*, "Oral arguments heard in New York ZEC case, state subsidies in spotlight", *Platts,* 12 March 2018, see https://www.platts.com/latest-news/electric-power/newyork/oral-arguments-heard-in-new-york-zec-case-state-21543045, accessed 20 May 2018.

1188 - *NW*, "New York Supreme Court to hear lawsuit challenging ZEC program".

Exelon, which also operates nuclear plants in New York, took a page out of Entergy's book and threatened to shut the Ginna and Nine Mile Point-1 reactors unless the state approves "a compensation plan for nuclear generators" that would "require all companies that sell electricity in the state to buy power from upstate nuclear plants at potentially above-market rates".[1189] The availability of ZECs for Ginna appeared to reverse Exelon's plan for closure.

The NYPSC ZEC plan requires that assigned nuclear power plants participate in the program through two six-year periods and sell the ZECs to the New York State Energy Research and Development Authority. In total, the ZEC is estimated to be worth US$8 billion over a 12-year period from 1 April 2017. With the 2016-purchase of FitzPatrick, Moody's said that Exelon "could receive another US$120 million pre-tax cash flow from [the credits], or about US$75 million of after-tax cash flow" in the first two years.[1190]

In response to the NYPSC Clean Energy Standard ZEC, a coalition of five electricity generators and the Electric Power Supply Association (EPSA) on 19 October 2016 filed a lawsuit in a New York State court calling for the halting of the "unlawful" plan. On 24 July 2017, the court dismissed the case against the PSC approval of ZEC's for nuclear plants.[1191]

Entergy's other unit in New York State is the Indian Point nuclear power plant, which has been more profitable because of the higher power prices in nearby New York City. However, operations at Indian Point have long been challenged on two crucial environmental requirements—a coastal zone management certification and a water permit application.[1192] On 9 January 2017, agreement was announced for the permanent closure of the two reactors.[1193] The agreement mirrors an arrangement reached between PG&E (Pacific Gas & Electric Co.) and stakeholders, including environment groups, over the planned closure of the two reactors at Diablo Canyon in California announced in 2016 (see previous WNISR editions).[1194] In the case of Indian Point, the early shutdown is part of a settlement under which the State has agreed to drop legal challenges and support renewal of the operating licenses for Indian Point.[1195] Entergy filed a license renewal application for both Indian Point operating units in April 2007, which were subse-

1189 - Jim Ostroff, "Exelon to shut Nine Mile Point-1, Ginna reactors if New York fails to OK compensation plan", *Platts*, 14 June 2016, see https://www.platts.com/latest-news/electric-power/washington/exelon-to-shut-nine-mile-point-1-ginna-reactors-21708658, accessed 6 August 2017.

1190 - *NW*, "FitzPatrick to shut if plan for credits thwarted, says entergy spokeswoman", 27 October 2016.

1191 - Environmental Defense Fund, "U.S. District Court Decides in Favor of New York's Clean Energy Standard" 25 July 2017, see https://www.edf.org/media/us-district-court-decides-favor-new-yorks-clean-energy-standard, accessed 20 May 2018, and

United States District Court Southern District Of New York, Case 1:16-cv-08164-VEC Document 159, see http://blogs.edf.org/climate411/files/2017/07/NY-ZEC-decision.pdf, accessed 20 May 2018.

1192 - Frans Koster, "Could Indian Point Fall Victim to Economics?", *NIW*, 10 June 2016.

1193 - Indian Point Energy Center, "Entergy, NY Officials Agree on Indian Point Closure in 2020-2021—Decision driven by sustained low power prices", Entergy, Press Release, 9 January 2017, see http://www.safesecurevital.com/entergy-ny-officials-agree-on-indian-point-closure-in-2020-2021/, accessed 15 May 2017; for complete transcript of the agreement signed 9 January 2017, see Riverkeeper, "Indian Point Agreement", see https://www.riverkeeper.org/wp-content/uploads/2017/01/Indian-Point-Closure-Agreement-January-8-2017.pdf, accessed 15 May 2017.

1194 - PG&E, "In Step With California's Evolving Energy Policy, PG&E, Labor and Environmental Groups Announce Proposal to Increase Energy Efficiency, Renewables and Storage While Phasing Out Nuclear Power Over the Next Decade", News Release, 21 June 2016, see https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20160621_in_step_with_californias_evolving_energy_policy_pge_labor_and_environmental_groups_announce_proposal_to_increase_energy_efficiency_renewables_and_storage_while_phasing_out_nuclear_power_over_the_next_decade, accessed 15 May 2017.

1195 - Indian Point Energy Center, "Entergy, NY Officials Agree on Indian Point Closure in 2020-2021—Decision driven by sustained low power prices", Entergy, Press Release, 9 January 2017, see http://www.safesecurevital.com/entergy-ny-officials-agree-on-indian-point-closure-in-2020-2021/, accessed 15 May 2017; for complete agreement, see Riverkeeper, "Indian Point Agreement", signed 9 January 2017, see https://www.riverkeeper.org/wp-content/uploads/2017/01/Indian-Point-Closure-Agreement-January-8-2017.pdf, accessed 15 May 2017.

quently subject to sustained challenge from citizens groups over the past ten years.[1196] Entergy invested over US$1 billion in the two reactors in recent years.[1197] According to the agreement, Indian Point Unit 2 will shut down no later than 30 April 2020 and Unit 3 no later than 30 April 2021.

Another plant under financial stress is the Davis Besse reactor in **Ohio**, long considered at risk of shutdown due to economic factors.[1198] Its operator FirstEnergy proposed a power-purchase agreement with the Public Utilities Commission of Ohio, which approved a special eight-year arrangement in March 2016[1199], which was blocked by the Federal Energy Regulatory Commission (FERC) a month later.[1200] Through 2016 and 2017, FirstEnergy continued to lobby for the establishment of Zero Emission Nuclear (ZEN) legislation that would support their Davis-Besse and Perry reactors, which could be worth an estimated US$300 million a year to the reactors. In October 2017, a fresh bill was introduced, the ZEN resource program, aimed at saving the Davis Besse and Perry reactors, leading FirstEnergy to claim that it "would increase the likelihood of keeping the plants operational throughout the life of the program."[1201] The bill reduces the amount FirstEnergy would receive over two consecutive periods of six years, from US$300 million in previous introduced legislation to US$180 million[1202] The Perry reactor was expected to operate at a profit of US$3.5/MWh during 2017-2019, while Davis Besse was at US$4.5/MWh through the same period. These figures do not include the additional income, if Ohio's emissions credits are finally approved.

As of 1 July 2018, the proposed legislation has made slow progress, but with no hearings since January 2018, despite appeals by the bill's sponsor to move forward following FirstEnergy's filing for bankruptcy.[1203] The legislation, if passed, is likely to be challenged in the courts, but it is possible that securing the credits will see the reversal of decisions to close the Perry and Davis Besse plants.

While the legislation in Ohio (and Pennsylvania) making slow progress, on 29 March 2018, FirstEnergy Solutions and the FirstEnergy Nuclear Operating Co. informed the Nuclear Regulatory Comission (NRC) and the Pennsylvania-New Jersey-Maryland Interconnection (PJM Interconnection) that it will close its nuclear power plants within three

1196 - Vivian Yee, Patrick McGeehan, "Indian Point Nuclear Power Plant Could Close by 2021", *New York Times*, 6 January 2017, see https://www.nytimes.com/2017/01/06/nyregion/indian-point-nuclear-power-plant-shutdown.html?_r=0, accessed 15 May 2017.

1197 - Tom Kauffman, "Indian Point 3's Operating License is Alive and Well", *NEI*, 10 December 2015, see http://neinuclearnotes.blogspot.jp/2015/12/indian-point-3s-operating-license-is.html, accessed 15 May 2017

1198 - Mark Cooper, "Power Shift: The Deployment of a 21st Century Electricity Sector and the Nuclear War To Stop It", Institute for Energy and the Environment, Vermont Law School, June 2015, see http://www-assets.vermontlaw.edu/Assets/iee/%20Power_Shift_Mark_Cooper_June_2015.PDF, accessed 25 May 2017.

1199 - John Funk, "FirstEnergy's Davis-Besse, Sammis power plants make money after all: FirstEnergy profits show", *Cleveland.com*, 27 April 2016, see http://www.cleveland.com/business/index.ssf/2016/04/firstenergys_davis-besse_sammi.html, accessed 25 May 2017.

1200 - Gavin Bade, "FERC blocks Ohio power plant subsidies for AEP and FirstEnergy", *Utility Dive*, 28 April 2016, see http://www.utilitydive.com/news/ferc-blocks-ohio-power-plant-subsidies-for-aep-and- firstenergy/418297/, accessed 16 June 2016.

1201 - Ohio Legislature "Senate Bill 128", 132nd General Assembly Regular Session S. B. No. 128 2017-2018, see https://www.legislature.ohio.gov/legislation/legislation-documents?id=GA132-SB-128, accessed 20 May 2018; and Andrew Cass, "New Ohio House Bill aims to subsidize state's nuclear power plants", *The News Herald*, 13 October 2017, see http://www.news-herald.com/general-news/20171013/new-ohio-house-bill-aims-to-subsidize-states-nuclear-power-plants, accessed 20 May 2018.

1202 - *NW*, "New Ohio legislation introduced to give financial support to nuclear plants", 19 October 2017.

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years. The companies currently plan to close Davis-Besse in 2020, while the Perry nuclear plant two-reactor Beaver Valley nuclear plant in 2021. FirstEnergy Solutions has a debt of US$2.8 billion to creditors and another US$1.7 billion to the parent company FirstEnergy Corp.[1204]

On 31 March 2018, FirstEnergy Solutions Corp. and six affiliated debtors each filed a voluntary petition for relief under Chapter 11 of the United States Bankruptcy Code in the Bankruptcy Court for the Northern District of Ohio.[1205] The company is currently under petition at the NRC due to its failure to secure sufficient decommissioning funds for its three nuclear plants.[1206] A 2017-estimate put decommissioning costs for the three nuclear plants at US$5.4 billion, with a current fund level of only US$2.5 billion.[1207]

The decision of First Energy Solutions is a further signal that just because reactors have obtained 20-year license extensions does not mean they will operate through the full license period. The 42 and 31-year-old Beaver Valley units 1&2 in 2009 were issued by the NRC 20-year license extensions to permit them to operate until 2036 and 2047 respectively.[1208] FirstEnergy had notified the NRC only in May 2017 that it planned to file a license extension in 2020 for the one unit Perry reactor, whose current license expires in 2026.[1209] The 41-year old Davis-Besse reactor, was granted an NRC license extension in 2015, to operate through 2037.[1210]

With slow progress in securing legislation in Ohio for emissions credits, on 25 April 2018, First Energy Solutions confirmed that it had submitted a certification letter to the NRC notifying that it will close Perry, Davis-Besse and Beaver reactors, while it also stated that they "are actively seeking policy solutions at the state and federal level as an alternative to retiring these plants, which we believe still have a crucial role to play in the reliability and resilience of our regional grid," stated Don Moul, president of First Energy Solutions Generation Companies and chief nuclear officer.[1211]

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ANNEX 5
DEFINITION OF CREDIT RATING BY THE MAIN AGENCIES

Moody's		S&P		Fitch		
Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	
Aaa	P-1	AAA	A-1+	AAA	F1+	Prime
Aa1		AA+		AA+		High grade
Aa2		AA		AA		
Aa3		AA-		AA-		
A1		A+	A-1	A+	F1	Upper medium grade
A2		A		A		
A3	P-2	A-	A-2	A-	F2	
Baa1		BBB+		BBB+		Lower medium grade
Baa2	P-3	BBB	A-3	BBB	F3	
Baa3		BBB-		BBB-		
Ba1	Not prime	BB+	B	BB+	B	Non-investment grade speculative
Ba2		BB		BB		
Ba3		BB-		BB-		
B1		B+		B+		Highly speculative
B2		B		B		
B3		B-		B-		
Caa1		CCC+	C	CCC	C	Substantial risks
Caa2		CCC				Extremely speculative
Caa3		CCC-				In default with little prospect for recovery
Ca		CC C				
C		D	/	DDD	/	In default
/				DD		
/				D		

ANNEX 6
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. 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. Mycle 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.

Anton Eberhard is a Professor Emeritus and Senior Scholar at the University of Cape Town's Graduate School of Business. His research and teaching focuses on governance and regulatory incentives to improve utility performance, the political-economy of power sector reform,

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HAN Wenke, Vice-Director-General of the International Forum for Clean Energy (IFCE, Macao), and Senior Advisor and Research Fellow of the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC) of China. He was Director General of NDRC's ERI from 2006 to August 2016. He served as a member of the Expert Advisory Committee of National Energy Commission. Also, he is a Director of China Economic and Social Council, a Professor of Northwestern Polytechnical University, and an Adjunct Professor of Zhejiang University. He has long been engaged in the career of energy policy research since 1982. His research covers the fields in China's national energy development strategies and plans, national energy security, sustainable energy policies, energy market reform, energy subsidies reform and global energy governance.

Phil Johnstone is a Research Fellow in the Science Policy Research Unit (SPRU), University of Sussex, U.K.. He has carried out research in a number of areas while at SPRU including the governance of discontinuation, disruptive innovation in the energy sector, industrial policy, and the role of war and the military in technological development. He has researched nuclear issues for the past ten years, with a particular focus on the U.K.'s nuclear new-build program. He is co-organizer of the ESRC seminar series 'nuclear futures' which focusses on nuclear waste in the U.K., and along with colleagues, he has given evidence on nuclear matters to inquiries conducted by the Department of Business Energy & Industrial Strategy (BEIS), The Welsh Affairs Committee, and the Department of Energy and Climate Change (DECC). He is a member of the Sussex Energy Group (SEG) and was the Tyndall Centre coordinator for the University of Sussex from 2014-2016.

Tadahiro Katsuta holds a PhD in plasma physics from Hiroshima University (1997). He is currently a Professor at Meiji University, Tokyo, Japan. During 2014-15 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 2008-09, he conducted research on multilateral nuclear fuel cycle systems as a Visiting Fellow at PSGS. During 200608, he carried out research at the University

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Andy Stirling is a Professor in the Science Policy Research Unit (SPRU) and co-director of the STEPS Centre at the University of Sussex. He has a background in the natural sciences, a master's degree in archaeology and social anthropology (Edinburgh) and a doctorate in science and technology policy (Sussex). An interdisciplinary researcher on the politics of science and technology, Andy formerly worked in the environment and peace movements and has also collaborated with a range of governmental, business and civil society organizations. A fellow of the U.K. Academy of Social Science, he has served on several U.K. and EU policy advisory committees on issues around energy, chemicals, biotechnology, environment and science policy.

Christian von Hirschhausen is Professor of Economics at the Workgroup for Economic and Infrastructure Policy (WIP) at Berlin University of Technology (TU Berlin), and Research Director at DIW Berlin (German Institute for Economic Research). He obtained a PhD in Industrial Economics from the Ecole Nationale Supérieure des Mines de Paris, and was previously Chair of Energy Economics and Public Sector Management University of Technology (TU Dresden). von Hirschhausen focuses on the regulation and financing of infrastructure sectors, mainly energy, and is a regular advisor to industry and policymakers, amongst them the World Bank, the European Commission, European Investment Bank, and several German Ministries. Von Hirschhausen also focusses on energy technologies, and is one of the coordinators of a research project on nuclear energy in Germany, Europe, and abroad, including the first independent monitoring of the decommissioning process of German nuclear power plants.

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 long-term 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.

ZHOU Jie, PhD, is Vice-Director-General and Secretary-General of the International Forum for Clean Energy (IFCE, Macao), a Director of China Economic and Social Council and Senior Research Fellow of Wuhan New Energy Research Institute. He received his PhD in international politics from Chinese Academy of Social Sciences and master's degree in international relations from China Foreign Affairs University. He also did advanced studies in the Law Department of Tokyo University and the International Politics Department of Beijing University. He has served as a visiting research fellow in Japan's Gakushuin. His research concerns energy economics and technology, public policies and comparative study of legal system. He has published several papers and works relating to political reform & regime transition, energy strategy & industry policy, and clean energy & energy conservation and environmental protection fields.

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.

ANNEX 7
ABBREVIATIONS

3/11	Fukushima Daiichi nuclear power plant accidents
AEC	Atomic Energy Council (Taiwan)
AECL	Atomic Energy of Canada Limited (Canada)
AFP	*Agence France Presse* French Press Agency
AGEB	Arbeitsgruppe Energiebilanzen-Working Group on Energy Balances (Germany)
AGR	Advanced Gas-cooled Reactor
ANDRA	Agence National pour la gestion des déchets radioactifs National Radioactive Waste Management Office (France)
ASN	Autorité de Sûreté Nucléaire Nuclear Safety Authority (France)
ATC	Centralized Temporary Storage for spent fuel
ATMEA	AREVA reactor Design (France)
BAEC	Bangladesh Atomic Energy Commission
BDEW	Bundesverband der Energie- und Wasserwirtschaft e.V. Federal Association of the Energy and Water Industries (Germany)
BEIS	Department for Business Energy & Industrial Strategy (U.K.)
BHAVINI	Bharatiya Nabhikiya Vidyut Nigam Limited Indian Nuclear Power Corporation Limited
BLRA	Base Load Recovery Act
BNEF	Bloomberg New Energy Finance
BP	Beyond Petroleum
BPE	Basic Plan for Long-term Electricity supply and demand
BWR	Boiling Water Reactor
CANDU	CANadian Deuterium Uranium — Canadian Reactor Design
CAREM	Central Argentina de Elementos Modulares — Argentinian Reactor Design
CCC	Committee on Climate Change (U.K.)
CCS	Carbon Capture & Storage
CEA	Commissariat à l'Énergie Atomique et aux Énergies alternatives (France) French Alternative Energies & Atomic Energy Commission or Central Electric Authority (India)
CEFR	China Experimental Fast Reactor
CEO	Chief Executive Officer
CfD	Contract for Difference
CFP	Cavendish Fluor Partnership
CGDD	Commissariat Général au Développement Durable General Commission for Sustainable Development (France)
CGN	China General Nuclear Power Corporation

CLP	Containment Liner Plate
CNDP	Commission Nationale du Débat Public National Commission for Public Debate (France)
CNIC	Citizens Nuclear Information Center (Japan)
CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
COL	Construction and Operating License
ComEd	Commonwealth Edison Company
CPUC	California Public Utilities Commission (U.S.)
CVTR	Carolinas-Virginia Tube Reactor (U.S.)
CWIP	Combined Works In Progress
DAE	Department of Atomic Energy (India)
DBE	Design Basis Earthquake
DEC	Dongfang Electric Corporation (China)
DECC	Department of Energy & Climate Change (U.K.)
DEEP	Department of Energy & Environmental Protection (U.S.)
DIW	Deutsches Institut für Wirtschaftsforschung German Institute for Economic Research, University of Technology (Berlin)
DOE	Department of Energy (U.S. or South Africa)
DPP	Democratic Progressive Party (Taiwan)
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EBRD	European Bank for Reconstruction and Development
EC6	Advanced Candu-6
EDF	Électricité de France
EGAT	Electricity Generating Authority of Thailand
EIA	Environmental Impact Assessment or Energy Information Administration (U.S.)
ENEC	Emirates Nuclear Energy Corporation
ENEL	Ente Nazionale per l'energia elettrica Italian National Entity for Electricity
ENSI	Eidgenössisches Nuklearsicherheitsinspektorat Swiss Federal Nuclear Safety Inspectorate
ENSREG	European Nuclear Safety Regulators Group
ENTSOE	European Network of Transmission System Operators
EPDC	Electric Power Development Company
EPH	Energeticky a Prumyslovy Holding Energy and Industry Holding — privately-held Czech-Slovak company
EPR	European Pressurized Water Reactor
EPSA	Electric Power Supply Association
EPZ	Elektriciteits Produktiemaatschappij Zuid-Nederland Electricity Production Company, South-Netherlands

ERI	Energy Research Institute of the Natural Resources Defense Council (U.S.)
ESG	Energy Service Group
ETC	Estimate to Complete
EU	European Union
EVN	Electricity of Vietnam
FANC	Federal Agency for Nuclear Control (Belgium)
FAO	Financial Accountability Office of Ontario (Canada)
FBR	Fast-Breeder Reactor
FEPC	Federation of Electric Power Companies (Japan)
FERC	Federal Energy Regulatory Commission (U.S.)
FOE	Friends of the Earth
FTE	Full Time Equivalent
FY	Financial Year
GCNEP	Global Centre for Nuclear Energy Partnership
GCR	Gas-Cooled Reactor
GDA	Generic Design Assessment
GDF	Gaz de France - now known as Engie
GDOS	Polish General Directorate for the Environment
GDR	German Democratic Republic
GTCC	greater-than-class-C
GWEC	Global Wind Energy Council
HCSTISN	High Commission on the Transparency and Information on Nuclear Safety
HDR	Heißdampfreaktor superheated steam reactor (Germany)
HPC	Hinkley Point C (U.K.)
HTR	High Temperature Gas Cooled Reactor
HWBLWR	Heavy Water-Moderated Boiling Light Water-Cooled Reactor
IAEA	International Atomic Energy Agency
ICC	International Chamber of Commerce
ID	Immediate Dismantling
IEA	International Energy Agency
IEAC	International Energy Advisory Council
IEEJ	Institute of Energy Economics of Japan
IFCE	International Forum for Clean Energy (Macao)
IGCAR	Indira Gandhi Centre for Atomic Research (India)
IPS	Integrated Project Schedule
IRENA	International Renewable Energy Agency
IRP	Integrated Resource Plan
IRSN	Institut de Radioprotection et de Sûreté Nucléaire Institute for Radiation Protection and Nuclear Safety (France)
ISFSI	Independent Spent Fuel Storage Installation

ISO	Independent System Operator
JAEA	Japan Atomic Energy Agency
JAEC	Japan's Atomic Energy Commission or Jordan Atomic Energy Commission
JAIF	Japan Atomic Industrial Forum, Inc.
JAVYS	Jadrova A VYradovacia Spolocnost — State owned Energy utility (Slovakia)
JESS	Jadrová energetická spoločnosť Slovenska Joint venture of the JAVYS (Slovakia) and ČEZ (Czech)
JPDR	Japan Power Demonstration Reactor
JPY	Japanese Yen
JSW	Japan Steel Works
KA-CARE	King Abdullah City for Atomic and Renewable Energy (UAE)
KAPP	Kakrapar (India)
KEPCO	Korea Electric Power Company or Kansai Electric Power Company (Japan)
KFEM	Korean Federation of Environmental Movements
KGHM	Copper Mining and Smelting Industrial Complex (Poland)
KHNP	Korea Hydro & Nuclear Power Company
KMT	Chinese Nationalist Party
KOFAC	Keep Our Future Afloat campaign
LCOE	Levelized Cost of Energy
LDP	Liberal Democratic Party (Japan)
LTE	Long-Term Enclosure or "Safe Strorage"
LTO	Long-Term Outage
LTS	Long-Term Shutdown
LULUCF	Land Use, Land-Use Change, and Forestry
LWR	Light-Water Reactors
MEAG	Municipal Electric Authority Of Georgia
METI	Ministry for Economy, Trade and Industry (Japan)
MHI	Mitsubishi Heavy Industries LTD
MHLW	Ministry of Health Labor and Welfare (Japan)
MISO	Midcontinent Independent System Operator
MIT	Massachusetts Institute of Technology (U.S.)
MOE	Ministry of the Environment (Japan)
MOEA	Ministry of Economic Affairs (Taiwan)
MOFA	Ministry of Foreign Affairs (Japan)
MoU	Memorandum of Understanding
MOX	uranium-plutonium mixed oxide fuel
MPSC	Michigan Public Service Commission
MVOW	Vestas Offshore Wind
NAO	National Audit Office (U.K.)
NCA	Nuclear Co-operation Agreement
NDA	Nuclear Decommissioning Authority (U.K.)

NDRC	National Development and Reform Commission (China)
NDF	Nuclear Damage Compensation and Decommissioning Facilitation Organization (Japan)
NDT	Nuclear Decommissioning Trust funds
NEA	National Energy Administration (China) or Nuclear Energy Agency of the OECD
NEB	National Energy Board (Canada)
NEI	*Nuclear Engineering International* (Publication) or Nuclear Energy Institute (U.S.)
NEK	Nuklearna Elektrarna Krško (Slovenia) Krško Nuclear Power Plant
NERC	North American Electric Reliability Organization (U.S.)
NESA	Nuclear Energy Skills Alliance (U.K.)
NGO	Non-Governmental Organization
NIC	Nuclear Industry Council (U.K.)
NIRS	Nuclear Information and Resource Service
NJZ	nová jadrová zdroj
NPCIL	Nuclear Power Corporation of India Ltd
NPP	Nuclear Power Plant
NPS	National Policy Statement
NPT	Non-Proliferation Treaty
NRA	Nuclear Regulatory Authority (Japan)
NRC	Nuclear Regulatory Commission (U.S.)
NRDC	Natural Resources Defense Council (U.S.)
NSSC	Nuclear Safety & Security Commission (South Korea)
NSSG	Nuclear Skills Strategy Group (U.K.)
NYPSC	New York Public Service Commission (U.S.)
OECD	Organisation for Economic Co-operation and Development
OFGEM	The Office of Gas and Electricity Markets (U.K.)
OKG	Oskarshamns Kraftgrupp AB (Sweden) Swedish Corporation
OL	Olkiluoto (Finland)
ONDRAF	Organisme National des Déchets Radioactifs et des Matières Fissiles Enrichies National Radioactive Waste Management Agency (Belgium)
ONR	Office for Nuclear Regulation (U.K.)
OPC	Oglethorpe Power Corporation (Georgia)
OPPD	Omaha Public Power District (U.S.)
ORS	Office of Regulatory Staff (U.S.)
OSART	Operational Safety Review Team
PAEC	Pakistan Atomic Energy Commission
PBO	Parent Body Organization
PFBR	Prototype Fast Breeder Reactor

PG&E	Pacific Gas & Electric Company (U.S.)
PGE	Polska Grupa Energetyczna Polish Energy Group
PHWR	Pressurized High Water Reactor
PJM	Pennsylvania-New Jersey-Maryland Interconnection LLC (U.S.)
PLEX	Plant Life Extension
PNAS	Proceedings of the National Academy of Sciences (U.S.)
PPA	Power Purchase Agreement
PPE	Pluriannual Energy Plan
PRIS	Power Reactor Information System, of the IAEA
PSC	Public Service Commission (Georgia, Michigan or New York, U.S.)
PSEG	Public Service Enterprise Group (U.S.)
PSGS	Program on Science and Global Security, Princeton University (U.S.)
PSOE	Partido Socialista Obrero Español Spanish Socialist Workers' Party
PTC	Production Tax Credits
PV	Photovoltaics
PWR	Pressurized Water Reactor
PZEM	Provinciale Zeeuwse Energie Maatschappij N.V. (Netherlands)
R&D	Research & Development
RAPP	Rajastan (India)
RBMK	Graphite-Moderated Reactor - Chernobyl Type
REES	Retail Energy Enterprise Solution
REN21	Renewable Energy Policy Network for the 21st Century
RfP	Request for Proposal
RPV	Reactor Pressure Vessel
RTO	Regional Transmission Organization
RVI	Reactor Internal Vessel
RWE	RWE AG — Rhine-Westphalia Power Utility (Germany)
S&P	Standard & Poor's
SAFCEI	Southern African Faith Communities Environment Institute
SALTO	Safety Aspects of Long-Term Operation
SAM	Severe Accident Management
SCE	Southern California Edison (U.S.)
SCE&G	South Carolina Electric & Gas (U.S.)
SDG&E	San Diego Gas & Electric (U.S.)
SEG	Sussex Energy Group (U.S.)
SFOE	Swiss Federal Office of Energy
SGHWR	Steam Generating Heavy Water Reacot
SIEAC	Seoul International Energy Advisory Council
SLC	Site License Companies

SLED	South Carolina Law Enforcement Divison
SMR	Small Modular Reactor
SNN	Societatea Nationala Nuclearelectrica (Romania)
SNPTC	Chinese State Nuclear Power Technology Corporation
SPI	State Power Investment
SPIC	State Power Investment Corporation
SPRU	Science Policy Research Unit, University of Sussex (U.K.)
SSM	Swedish Radiation Safety Authority
STUK	Radiation and Nuclear Safety Authority (Finland)
TEPCO	Tokyo Electric Power Company (Japan)
TMI	Three Mile Island
TU	University of Technology
TVA	Tennessee Valley Authority (U.S.)
TVO	Teollisuuden Voima's (Finland)
U.K.	United Kingdom
U.S.DOE	Department of Energy (U.S.)
U.S.EIA	Energy Information Administration (U.S.)
UAE	United Arab Emirates
UCS	Union of the Concerned Scientists
UKERC	U.K. Energy Research Council or U.K. Energy Research Centre
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNHRC	United Nations Human Rights Council
VRE	Variable Renewable Energy
VVER	Vodo-Vodianoï Energuetitcheski Reaktor Russian Pressurized Water Reactor Design
WIP	Workgroup for Economic and Infrastructure Policy, Berlin University of Technology (Germany)
WNA	World Nuclear Association
WNISR	World Nuclear Industry Status Report
WNN	*World Nuclear News*
WSJ	*Wall Street Journal*
ZEC	Zero Emission Credits
ZEN	Zero-emission nuclear resource Program

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/l	Becquerel per litre
Bq/km²	Becquerel per square kilometer
Bq/m²	Becquerel per square meter
PBq	Petabecquerel (10^{15} Becquerel)
Gy	gray (derived unit of ionizing radiation dose; defined as the absorption of one joule of radiation energy per kilogram of matter)
Person-gray	unit of collective dose for specific organ exposures
mSv	millisievert
mSv/h	millisievert per hour
person-Sv	unit of collective dose for whole body exposures
Sv	Sievert
Sv/h	Sievert per hour
Sv/y	Sievert per year

ANNEX 8
STATUS OF NUCLEAR POWER IN THE WORLD

Table 20 | Status of Nuclear Power in the World (as of 1 July 2018)

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	2	1 033	1	27.8/24.1	1	4.5% (-)	1.7% (=)
Armenia	1	375		38.5		32.5% (+)	?
Bangladesh	-	-		-	1		
Belarus	-	-		-	2		
Belgium	7	5 918		38.3		49.9% (-)	15.3 (=)
Brazil	2	1 884		27.1		2.7% (=)	1.2 (=)
Bulgaria	2	1 926		28.8		34.3% (=)	
Canada	19	13 554		35		14.6% (=)	6.25 (=)
China	41	38 154	1	7.1	16	3.9% (=)	1.8% (=)
Czech Republic	6	3 930		27		33.1% (+)	15.4% (+)
Finland	4	2 769		39.3	1	33.2% (=)	18.6% (=)
France	57	61 800	1	33.4	1	71.6% (=)	37.9% (=)
Germany	7	9 515		31.8		11.6% (-)	5.1% (=)
Hungary	4	1 889		33.0		50% (-)	15.7% (=)
India	19	5 761	2	21.3/21	7	3.2% (=)	1.1% (=)
Iran	1	915		6.8		2.2% (=)	0.6% (=)
Japan	9	8 706	26	28/28.9	1	3.6% (+)	1.4% (=)
Mexico	2	1 552		26.4		6% (=)	1.3% (=)
Netherlands	1	482		45,0		2.9% (=)	1.4% (=)
Pakistan	5	1 320		14.9	2	6.2% (+)	2.3% (=)
Romania	2	1 300		16.5		17.6% (=)	7.7% (=)
Russia	37	28 238		29.7	5	17.8% (=)	6.6% (=)
Slovakia	4	1 814		26.3	2	54% (=)	
Slovenia	1	688		36.7		39.1% (+)	
South Africa	2	1 860		33.6		6.7% (=)	3% (=)
South Korea	24	22 494		20.6	4	27.1% (-)	11.3% (-)
Spain	7	7 121		33.4		21.2% (=)	9.5% (=)
Sweden	8	8 629		37.9		39.6% (=)	27.3% (=)
Switzerland	5	3 333		43.3		33.4% (=)	17.3% (=)
Taiwan	5	4 448	1	36.8/36		9.3% (-)	4.4% (-)
Turkey	-	-		-	1		
UAE	-	-		-	4		
U.K.	15	8 918		34.3		19.3% (=)	8.3% (=)
Ukraine	15	13 107		29.4		55.1% (+)	23.7% (+)
USA	99	99 979		38.1	2	20% (=)	8.6% (=)
EU	**125**	**116 699**	**1**	**33.4**	**4**	**25.3% (=)c**	**11.1% (=)**
World	**413**	**363 412**	**32**	**29.7/29.9**	**50**	**10.3% (=)c**	**4.4% (=)**

Notes

a - Including reactors in LTO/Excluding reactors in LTO (when different)

b - From IAEA-PRIS, "Nuclear Share of Electricity Generation in 2017", as of 1 July 2018

c - From BP, "Statistical Review of World Energy", 2018

Sources: WNISR2018, IAEA-PRIS, BP, 2018

ANNEX 9
NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION"

Table 21 | Nuclear Reactors in the World "Under Construction" (as of 1 July 2018)

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
Argentina	**1**	**25**				
Carem25		25	CAREM (PWR)	08/02/2014	2020 (operation)[1]	yes
Bangladesh	**1**[2]	**1 080**				
Rooppur-1		1080	VVER-1200	30/11/2017	2023[3]	
Belarus	**2**	**2 218**				
Belarusian-1		1109	VVER V-491	06/11/2013	Q4 2019[4]	yes
Belarusian-2		1109	VVER V-491	03/06/2014	7/2020[5]	?
China	**16**	**15 450**				
CFR-600		600	FBR	29/12/2017	2023 (commercial operation)[6]	
Fangchenggang-3		1000	HPR-1000	24/12/2015	2022[7]	
Fangchenggang-4		1000	HPR-1000	23/12/2016	2022[8]	
Fuqing-5		1000	HPR-1000	07/05/2015	6/2020 (completion)[9]	yes
Fuqing-6		1000	HPR-1000	22/12/2015	2021[10]	?
Haiyang-1		1000	AP-1000	24/09/2009	2018[11]	yes
Haiyang-2		1000	AP-1000	21/06/2010	2019[12]	yes
Hongyanhe-5		1000	ACPR-1000	29/03/2015	2020[13]	
Hongyanhe-6		1000	ACPR-1000	24/07/2015	2021[14]	
Sanmen-2		1000	AP-1000	17/12/2009	2018[15]	yes
Shidao Bay-1		200	HTR-PM	01/12/2012	2019?[16]	yes
Taishan-2		1660	EPR-1750	15/04/2010	2019[17] (commercial)	yes
Tianwan-4		990	VVER V-428M	27/09/2013	2019[18]	yes
Tianwan-5		1000	CNP-1000	27/12/2015	2020[19]	
Tianwan-6		1000	CPR-1000	07/09/2016	2021[20]	
Yangjiang-6		1000	ACPR-1000	31/12/2013	2019[21]	yes
Finland	**1**	**1 600**				
Olkiluoto-3		1600	EPR	12/08/2005	5/2019[22]	yes
France	**1**	**1 600**				
Flamanville-3		1600	EPR	03/12/2007	2020[23]	yes
India[24]	**7**	**4 824**				
Kakrapar-3		630	PHWR-700	22/11/2010	2019[25]	yes

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
Kakrapar-4		630	PHWR-700	22/11/2010	2020[26]	yes
Kudankulam-3		917	VVER V-412	29/06/2017	Mid-2023[27]	
Kudankulam-4		917	VVER V-412	23/10/2017	2023[28]	
PFBR		470	FBR	23/10/2004	2018[29]	yes
Rajasthan-7		630	PHWR	18/07/2011	2020[30]	yes
Rajasthan-8		630	PHWR	30/09/2011	2021[31]	yes
Japan	**1**	**1 325**				
Shimane-3		1325	ABWR	12/10/2007	?[32]	yes
Pakistan	**2**	**2 028**				
Kanupp-2		1014	ACP-1000	20/08/2015	2020[33] (expected operation)	
Kanupp-3		1014	ACP-1000	31/05/2016	2021[34] (expected operation)	
Russia	**5**	**3 378**				
Akademic Lomonosov-1		32	KLT-40S 'Floating'	15/04/2007	2019[35]	yes
Akademic Lomonosov-2		32	KLT-40S 'Floating'	15/04/2007	2019[36]	yes
Kursk 2-1		1115	VVER V-510	29/04/2018	2022	
Leningrad 2-2		1085	VVER V-491	15/04/2010	2022[37] (commissioning)	yes
Novovoronezh 2-2		1114	VVER V-392M	12/07/2009	2020[38] (commissioning)	yes
Slovakia	**2**	**880**				
Mochovce-3		440	VVER V-213	01/01/1985	End 2018[39]	yes
Mochovce-4		440	VVER V-213	01/01/1985	End 2019[40]	yes
South Korea	**4**	**5 360**				
Shin-Hanul-1		1340	APR-1400	10/07/2012	12/2018?[41] (commercial operation)	yes
Shin-Hanul-2		1340	APR-1400	19/06/2013	10/2019[42] (commercial operation)	yes
Shin-Kori-4		1340	APR-1400	19/09/2009	2019?[43]	yes
Shin-Kori-5		1340	APR-1400	03/04/2017	3/2022[44] (commercial operation)	yes
Turkey	**1**	**1 114**				
Akkuyu-1		1114	VVER V-491	03/04/2018	2023[45]	
UAE	**4**	**5 380**				
Barakah-1		1345	APR-1400	19/07/2012	2020[46]	yes
Barakah-2		1345	APR-1400	30/05/2013	2020?[47]	yes
Barakah-3		1345	APR-1400	24/09/2014	2021?[48]	yes
Barakah-4		1345	APR-1400	30/07/2015	2021?[49]	yes?
USA	**2**	**2 234**				
Vogtle-3		1117	AP-1000	12/03/2013	11/2021[50]	yes
Vogtle-4		1117	AP-1000	19/11/2013	11/2022[51]	yes
World	**50**	**48 496**		**1985-2018**	**2018-2023**	**33-36**

Notes

1 - Delayed. According to CNEA, Carem is now expected to be in operation in 2020, a further delay of around one year since WNISR2017; see *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.

2 - Construction of a second unit at Rooppur officially started in July 2018; see Rosatom, "Main construction of the 2nd Unit of Rooppur NPP begins with the 'First Concrete' ceremony", 15 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.

3 - See Rosatom, "First concrete poured at the constructed Rooppur NPP site (Bangladesh)", 30 November 2017, see http://rosatom.ru/en/press-centre/news/first-concrete-poured-at-the-constructed-rooppur-npp-site-bangladesh/, accessed 30 November 2017.

4 - Delayed. Grid connection is now expected in last quarter 2019, date of expected Commercial Operation in WNISR2017; see *Belta*, "Belarusian nuclear power plant to give electricity to national power grid in Q4 2019", *Belarus News*, 28 March 2018, see http://eng.belta.by/economics/view/belarusian-nuclear-power-plant-to-give-electricity-to-national-power-grid-in-q1-2019-110418-2018, accessed 24 April 2018.

5 - *Belta*, "Belarusian nuclear power plant to give electricity to national power grid in Q4 2019", *Belarus News,* 28 March 2018, (see previous note).

6 - CFR-600 is not listed as under construction by 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 and 2017 refer to 2022 as "Expected Date of Commencement of Operation" for both units; see CGN, "2016 Annual Report", 2017, see http://en.cgnp.com.cn/encgnp/c100882/201709/0737beb93b87450b849940d45152ff0a/files/b487c045188a48bba6f459b9577a0e1d.pdf, accessed 28 April 2018. As of May 2018, WNA's table "Nuclear reactors under construction and planned" indicates 2019-20 for operation/grid connection for Fangchenggang-3 and -4; and WNA, "Nuclear Power in China", May 2018, see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx, accessed 20 May 2018. Other 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.

8 - See previous note.

9 - CNNC Chairman quoted by *Reuters* in March 2016, said that hopes are that construction of the first Hualong (Fuqing-5) will be completed by June 2020. Other sources (WNA, *NEI*) keep 2019 as completion date; see *Reuters*, "China's debut Westinghouse reactor delayed until June 2017", 9 March 2016, see http://www.reuters.com/article/us-china-parliament-nuclear-idUSKCN0WB09F, accessed 24 June 2016. No change since WNISR2016, already delayed from original startup date of 2019.

10 - Probably delayed. 2020 was the completion date announced at construction start; 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. Other sources in China point to dome hosting only implemented in March 2018, earliest expected grid connection date would be 2021.

11 - Delayed. Haiyang-1 was supposed to start up in 2014. Fuel loading started in late June 2018. No further delay announced since WNISR2017; see SNPTC, "Fuel Loading Begins in Haiyang Nuclear Power Plant Unit 1", Chinese State Nuclear Power Technology Corporation, 22 June 2018, see http://www.snptc.com.cn/en/xwzx/hdyw/201806/t20180622_18786.html, accessed 22 July 2018.

12 - Probably further delayed. Although NNSA granted permission for fuel loading, which would allow the reactor to be connected to the grid in 2018, according to SNPTC, startup will only take place in 2019. See SNPTC-WEC, "Chinese AP1000s pass commissioning milestones", 22 June 2018, see http://www.swnptsc.com/en/news/100721_for_detail.htm, accessed 5 August 2018.

13 - At construction start of Hongyanhe-5, it was announced that Honghyane-5 & -6 would be completed by 2021. Operation of Hongyanhe-5 was later reported to start in November 2019, change introduced in WNISR2017; see *NEI*, "Dome installed at China's Hongyanhe-5", 17 April 2017, see http://www.neimagazine.com/news/newsdome-installed-at-chinas-hongyanhe-5-5787690, accessed 6 August 2017. However CGN's annual report for 2017 still refers to second semester 2020 as "Expected Date of Commencement of Operation". CGN, "Annual Report 2017", 2018, see http://en.cgnp.com.cn/encgnp/c100882/201803/13be53b5a24f4de38b096dfe58847bc6/files/4fb5665ed8604110a89193d9fa7b2675.pdf. WNISR2018 reinstates 2020.

14 - At construction launch of Honghyane-5, *WNN* wrote "the company aims to have Honghyane-5 & -6 in operation by 2021." Later, as it announced construction start of Hongyanhe6, WNN used 8/2020 as startup date. CGN's annual report for 2017 still refers to 2021 as "Expected Date of Commencement of Operation". See previous note. WNISR2018 reinstates 2021 as target date, although sources in China indicate that grid connection could be achieved in 2020.

15 - Delayed. Fuel loading of Sanmen-1, which was to take place in 2017 started in April 2018, and the reactor was connected to the grid on 30 June 2018. It is unclear how this will affect Sanmen-2's schedule. SNPTC, reported in March 2018 that "AP1000 Self-reliance Program Supporting Project Sanmen Unit 2 Hot Functional Test (HFT) was successfully completed on Jan. 31, which officially brings Unit 2 into Fuel Load preparation phase". Scheduled startup date remains 2018 but will possibly be further delayed compared to WNISR2017; see *Reuters*, "China nuclear reactor delayed again on 'safety concerns': China Daily", 13 February 2018, see https://www.reuters.com/article/us-china-nuclear/china-nuclear-reactor-delayed-again-on-safety-concerns-china-daily-idUSKBN1FX02P, accessed 9 April 2018; and SNPTC, "Sanmen Unit 2 HFT Completed", 7 March 2018, see http://www.snptc.com.cn/en/xwzx/hdyw/201803/t20180307_18616.html, accessed 22 July 2018.

16 - Further delayed. According to sources in China, startup in 2018 would be difficult to achieve, with equipment remaining to be installed.

17 - Delayed many times. According to CGN announcement in December 2017, commercial operation of Taishan-2 is expected in 2019, a further delay compared to "first half of 2018" in WNISR2017; see CGN, "Inside Information: Construction Progress of Taishan Nuclear Power Generating Units", 29 December 2017, see http://en.cgnp.com.cn/encgnp/c100884/201712/883ae364eec7473fb27158348af7c13a/files/37c9323477e249f2baab22c63df65dd7.pdf, accessed 11 April 2018.

18 - Delayed. Hot functional tests have started at Tianwan-4. Startup is expected in early 2019. See *WNN*, 28 March 2018. No further delay since WNISR2017.

19 - 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 14 August 2018.

20 - WNISR, "China: Grid Connection for Fuqing-3 and Construction Start on Tianwan-6". See previous note.

21 - CGN, "Annual Report 2017", 2018, see http://en.cgnp.com.cn/encgnp/c100882/201803/13be53b5a24f4de38b096dfe58847bc6/files/4fb5665ed8604110a89193d9fa7b2675.pdf, accessed 30 May 2018.

22 - Delayed several times from its original planned commissioning in 2009. According to the new schedule provided in June 2018, grid connection is now expected in May 2019, and regular electricity generation in September 2019. A delay of about one year compared to WNISR2017. TVO, "OL3 EPR's regular electricity generation starts in September 2019", Press Release, 13 June 2018, see https://www.tvo.fi/news/2000, accessed 13 June 2018.

23 - Delayed several times from its original planned startup date of 2012. In July 2018, EDF announced that fuel loading was scheduled for the 4th quarter of 2019; see 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. A delay of one year since WNISR2017. (See France Focus).

24 - Unless otherwise mentioned, dates for India relates to "expected completion" from Jitendra Singh, "Lok Sabha—Unstarred Question No.4226—Issues Concerning Installation Of New NPPs—Answer by The Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office", Department of Atomic Energy, Government of India, 21 March 2018, see http://dae.nic.in/writereaddata/parl/budget2018/lsus4226.pdf, accessed 15 May 2018.

25 - Delayed several times. In WNISR2017, commercial operation for Kakrapar-3 was expected in 2018. Completion is now expected in 2019.

26 - Delayed several times. In WNISR2017, commercial operation was expected in 2018. Completion is now expected in 2020.

27 - No indication of delay.

28 - Construction of Kudankulam-4 started in October 2017 (introduced in PRIS in May 2018); see NPCIL, "Major achievements, significant developments and important events for the month of October 2017", 2 November 2017, see http://www.npcil.nic.in/WriteReadData/userfiles/file/news_02nov2017_02.pdf, accessed 9 May 2018. While the Department of Atomic Energy provided 2023 as "expected completion date", ASE quotes 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.

29 - Delayed several times. Official startup date remains 2018, but a report in the Times of India says that the PFBR "is expected to achieve criticality either in late 2018 or early 2019"; see *The Times of India*, "Kalpakkam Fast Breeder Test Reactor achieves 30 MW power production", 27 March 2018, see https://timesofindia.indiatimes.com/city/chennai/kalpakkam-fast-breeder-test-reactor-achieves-30-mw-power-production/articleshow/63480884.cms, accessed 6 April 2018.

30 - Delayed. Completion of Rajasthan-7 expected in 2020, a further delay of two years compared to WNISR2017.

31 - Delayed. Completion of Rajasthan-8 expected in 2021, a further delay of two years compared to WNISR2017.

32 - Construction status unclear. Chugoku "took the first step" toward Shimane-2 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, see http://www.asahi.com/ajw/articles/AJ201805220043.html, accessed 22 May 2018. Still no clear date for startup.

33 - PNRA, "Nuclear Safety - Table-1: Nuclear Installations", Pakistan Nuclear Regulatory Authority, July 2018, see http://www.pnra.org/n-safety.html, accessed 28 July 2018. Change from WNISR2017, which used 2021 as startup date.

34 - PNRA, "Nuclear Safety—Table-1: Nuclear Installations", July 2018. Change from WNISR2017 which used 2022 as startup date.

35 - Rosatom, "The world's only floating power unit 'Akademik Lomonosov' takes the sea", Press Release, 28 April 2018, see http://rosatom.ru/en/press-centre/news/the-world-s-only-floating-power-unit-akademik-lomonosov-takes-the-sea/, accessed 30 April 2018.

36 - Rosatom, "The world's only floating power unit 'Akademik Lomonosov' takes the sea", Press Release, 28 April 2018.

37 - Delayed several times. *TASS* agency reported in February 2018, that Russia was ready to postpone 'Commissioning of two Nuclear Plants'. Commissioning of Leningrad 2-2, planned for February 2020, would be postponed by two years; see *NucNet*, "Russia Ready To Postpone Commissioning Of Two Nuclear Plants, Says Official Agency", 5 February 2018, see https://

www.nucnet.org/all-the-news/2018/02/05/russia-ready-to-postpone-commissioning-of-two-nuclear-plants-says-official-agency, accessed 7 February 2018.

38 - Delayed several times. TASS agency reported in February 2018, that Russia was ready to postpone "Commissioning of two Nuclear Plants". Commissioning of Novovoronezh 2-2, planned for January 2019, would be postponed by one year. (see previous note)

39 - Delayed several times. 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; see SE, "Shareholders approved the 2017 – 2021 Strategic Plan", 29 March 2017, see https://www.seas.sk/article/shareholders-approved-the-2017-2021-strategic-plan/305, accessed 30 March 2017. Date confirmed by SEAS in February 2018; see SEAS, "Mochovce: Unit 3 connected to the power grid", 12 February 2018, see https://www.seas.sk/article/mochovce-unit-3-connected-to-the-power-grid/342, accessed 19 February 2018. No change since WNISR2017.

40 - Delayed several times. 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. (SEAS) on 28 March 2017, operation of Mochovce-4 is expected by the end of 2019; see previous reference. Date confirmed by SEAS in February 2018. see previous note. No change since WNISR2017.

41 - Delayed. In January 2018, KHNP's dedicated webpage for Shin-Hanul-1 announced a change in Commercial Operation (December 2018), with fuel loading to take place in April 2018, which has not taken place as of 1 July 2018. A delay of at least 8 months compared to WNISR2017; see *The Korea Herald*, "Completion of new reactors delayed by quake-safety inspections", 8 February 2018, see http://www.koreaherald.com/view.php?ud=20180208000252, accessed 30 April 2018; and KHNP, "Nuclear Power Construction—Shin-Hanul #1,2", 30 April 2018, see http://cms.khnp.co.kr/eng/content/547/main.do?mnCd=EN03020303, accessed 17 May 2018.

42 - Delayed several times. In January 2018, KHNP's dedicated webpage for Shin-Hanul-2 announced a change in Commercial Operation (October 2019) a delay of 8 months compared to WNISR2017.

43 - Delayed several times. In February 2018, the *Korean Herald* reported that "The Shin Kori No. 4 was scheduled to be fueled and put on trial operation last year, ahead of completion in September this year. The Korea Hydro & Nuclear Power Co. (KHNP) said the reactor may not meet the target date due to added inspections, and the delay would affect the two other new power plants."; see *The Korea Herald*, "Completion of new reactors delayed by quake-safety inspections", 8 February 2018, see http://www.koreaherald.com/view.php?ud=20180208000252, accessed 30 April 2018. As of July 2018, fuel loading has not taken place, KHNP's dedicated page has not been modified and no new date provided; and KHNP, "Nuclear Power Construction—Shin Kori #3,4", 30 June 2018, see http://cms.khnp.co.kr/eng/content/546/main.do?mnCd=EN03020302, accessed 15 July 2018. WNISR2018 tentatively moved startup to 2019.

44 - Delayed. Construction officially started in April 2017, suspended in July to resume in October. Commercial operation at construction start was October 2021, it is now expected in March 2022, a five-month delay; see KHNP, "Nuclear Power Construction—ShinKori #5,6", various dates, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, accessed 14 August 2019.

45 - See Rosatom, "Presidents of Russia and Turkey Vladimir Putin and Recep Tayyip Erdoğan kicked off large-scale construction of Akkuyu NPP", 4 April 2018, see http://rosatom.ru/en/press-centre/news/presidents-of-russia-and-turkey-vladimir-putin-and-recep-tayyip-erdo-an-kicked-off-large-scale-const/, accessed 4 April 2018.

46 - Delayed. A further delay of 1.5 to 2 years since WNISR2017. In May 2017, startup of Barakah-1 was first postponed to 2018. In May 2018, the revised 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", Press Release, 28 May 2018, see http://www.nawah.ae/en/news/NextphaseofpreparationsforBarakah.html, accessed 29 May 2018.

47 - Delayed. No new date for Barakah-2 in revised schedule (see previous note). WNISR2018 uses 2020 as startup date for Barakah-2, a two-year delay compared to original schedule.

48 - Delayed. No new date for Barakah-3 in revised schedule (see previous note). WNISR2018 uses 2021 as startup date for Barakah-3, a two-year delay compared to original schedule.

49 - Delayed? No new date for Barakah-4 in revised schedule (see previous note). WNISR2018 uses 2021 as startup date for Barakah-4, a delay of one year compared to original schedule.

50 - Further delayed. According to Georgia Power, Vogtle-3 is now expected online in November 2021, a further delay of over 2 years compared to WNISR2017; see Georgia Power, "Georgia Power will move forward with Vogtle 3 & 4 project", 21 December 2017, see https://southerncompany.mediaroom.com/2017-12-21-Georgia-Power-will-move-forward-with-Vogtle-3-4-project, accessed 16 May 2018.

51 - Further delayed. According to Georgia Power, Vogtle-4 is now expected online in November 2022, a further delay of over 2 years compared to WNISR2017. (see previous note).